THE OHIO JOURNAL OF SCIENCE

VOL. 61 JULY, 1961 No. 4

STRUCTURE OF LIQUIDS AND SOLUTIONS

GLENN H. BROWN†

Department of Chemistry, Kent State University, Kent, Ohio

As we focus our attention on the liquid state and on solutions, I shall make a few comments on the relation of the liquid state to the gaseous and solid states of matter. The space in a system constituting a gas is sparsely occupied. Owing to their thermal energy, the molecules of a gas are in continual motion and collide occasionally with one another and with the walls of their container but rebound without loss of energy to the system. Because of the near-independence of the particles of a gas, a gas can expand to an unlimited volume. Thus, the distinctive feature of the gaseous state is that its particles (atoms or molecules) are substantially independent of each other except for occasional collisions.

A primary property of a liquid is that it occupies a certain amount of space; it has a definite density at a given temperature and pressure. The particles of a liquid are close enough to be in contact with one another. In contrast to the gas, the attraction of one molecule to its immediate neighbor is high and, when a liquid is poured, it maintains a constant volume. Furthermore, the molecules in a liquid do not have particular partners as they do in solids, and this irregularity allows a greater degree of tolerance in molecular arrangement. Thus, the liquid state is characterized by its irregularity or indefiniteness in molecular arrangement.

If one could use an experimental technique which would be on an observational time-scale small enough, the measured properties of a liquid would likely match those of a solid. One experimental observation which supports this prediction is that ultrasonic waves of a sufficiently high frequency can set up shear waves in liquids as they do in solids. Also, it has been shown by neutron beam diffraction that a molecule in a liquid has time to vibrate 10 to 100 times before the structure changes. In this short time-scale the structure of the liquid is physically but not geometrically like that of a crystal.

If the thermal agitation of a liquid is reduced to a point where it is insufficient to break the attractive forces between molecules, then at temperatures below this, bonds between molecules are permanently maintained and collections of molecules take on a rigidity, thus giving the system a bridgework of bonds. The pattern of such a framework may be random or ordered; the ordered arrangement is the one of lesser energy and, therefore, tends to develop. The ordered arrangement is, of course, the crystalline state. Thus, the dominant feature of the crystalline state, in contrast to the gaesous and the liquid states, is the bonding forces between its molecules that give this state its orderly arrangement. Thermal agitation tends to disturb this order in the solid so that, when the temperature is high enough and the average thermal energy of a molecule exceeds its bonding energy, the molecules escape from one another's influence and the solid melts.

Another interesting difference between solids and liquids is that the melting point of a pure solid, which does not show liquid crystallinity, is sharp; however,

†Presidential Address delivered at the 70th Annual Meeting of The Ohio Academy of Science, at the University of Cincinnati, Cincinnati, Ohio, on April 21, 1961.

a liquid cooled through the freezing point with appropriate precautions does not solidify, nor do its properties change greatly in passing through the temperature at which it normally freezes. A conclusion one might draw here is that the solid and liquid are alternative ways of arranging molecules. When a crystal is heated short of the melting point, the atoms increase their vibration and move farther apart but do not change partners. On the other hand, a liquid upon being heated shows a change in identity and number of neighbors about a reference molecule. Thus, a liquid may be described as a continuous series of phases, each "stable" at a particular temperature.

From these few remarks about the properties of liquids and solids one might conclude that a liquid near its freezing point has a structure which is not very different from that of a solid. At this point there must be about the same number of molecules surrounding a reference molecule in the liquid state as there are when the material is in the solid state. In characterizing the three states of matter, one can say that crystalline solids have regular and coherent structure; liquids have irregular and coherent structure; and gases have irregular and incoherent structure.

In much of the vast literature on the liquid state there has been an effort to explain the thermal, mechanical, and other properties of liquids. The results of these studies have brought little success in accounting for the structural character of the liquid state when one considers, in a relative way, the successes of the molecular theory of gases and of the lattice theory of crystalline solids. This lack of success evidently lies in the fact that it is extremely difficult to construct a model of the liquid state which corresponds to its structure and at the same time to have a model which yields itself to mathematical computation.

A number of theories of liquids have been proposed. These are the kinetic multiple contact theory of Kirkwood (1935, 1939, 1946) and of Born and Green (1946); the cell theory of Lennard-Jones and Devonshire (1937, 1938); the cybotactic hypothesis of Stewart (1930); and the hole theories of Frenkel (1946), of Eyring (1936), Eyring and Hirschfelder (1937), and of Furth and his coworkers (1939, 1941). The last three theories assume that a large part of the liquid has a crystalline arrangement, which is in contradiction with the experimental facts that liquids lack a long-range order.

None of the theories mentioned above have made much use of the experimental evidence that has accumulated, or is accumulating, on the actual molecular structure of liquids and solutions. The first papers on the structure of liquids by x-ray methods are the classical studies of Prins (1935), of Stewart (1930) and of Morgan and Warren (1938). These early papers have been followed by a number of others on the structure of liquids, such as, neutron diffraction of liquids (Thewlis, 1950), structure of solutions (Brady, 1958a, b; Brady and Krause, 1957; Strauss, 1960; Ritter, personal communication), and the structure of formamide (Brown and DeSando, unpublished) by the x-ray method and by the microwave technique (Costain and Dowling, 1960). All data show liquids and solutions possess short-range order. This short-range order is practically limited to molecules in the first, second, and third spheres around a given molecule; i.e., beyond two or three molecular diameters the arrangement in one place in the liquid has no effect on that in another.

Many attempts have been made to explain the structure of ionic solutions. Some of the big advances in recent years in our knowledge of these systems come from classical papers such as those by Debye and Hückel (1923a, b) and by Mayer (1950). Much of the early evidence relative to the structure of solutions is based on such measurements as conductance, viscosity, boiling point, and freezing point. The use of x-rays to study the structure of solutions is relatively new. Stewart (1939) made some attempt to use x-rays in the study of the structure of ionic solutions and concluded that the electrostatic field of the ions broke down

the tetrahedral structure of water. Prins (1935) made some observations on how the x-ray diffraction patterns of solutions could be correlated with various structural elements of the solution. He assumed that the x-ray scattering in a solution was due to (1) the water structure, (2) the water-ion structure and (3) the ions alone. Bernal and Fowler (1933) concluded the effect of ions in solution was to either increase or decrease the structural regularity of the solution depending on whether the ions were solvated or unsolvated. Several workers have carried out radial distribution functions for a number of solutions including sodium hydroxide, hydrochloric acid, and phosphoric acid (Finbak and Bastiansen, 1943; Devik et al., 1944; Bastiansen and Finbak, 1944). Apparently the resolution of the distribution functions was not good enough for them to attempt to draw any quantitative results from their data. Brady has studied the structure of lithium chloride (1958a), potassium chloride (Brady and Krause, 1957), potassium hydroxide (1958a), and iron(III) chloride (1958b) solutions. Ritter (personal communication) has studied the structure of barium iodide solutions.

Since my students and I have used x-ray methods in some of our studies, I shall focus our attention on the knowledge of the structure of liquids and solutions which can be gained from the experimental and theoretical procedures of x-ray diffraction. Occasionally, other experimental methods will be mentioned to supplement the evidence from this method.

This paper is a general review, written for an audience representing different scientific disciplines, and the details of the theoretical aspects of the x-ray method have been omitted; only the results of the findings are discussed. The interested reader may find the theory described in many of the references cited at the end of this article.

Instrumentation

Let us take a very brief look at the experimental practices of x-ray methods. Details of the equipment used for x-ray studies may be found in many standard textbooks and monographs on the subject. It will suffice here to say that there are two common types of instrumentation available for x-ray diffraction studies. The simplest and least expensive type is to record the x-ray diffraction pattern on photographic film, using a powder camera. A more elaborate method is to detect the diffracted radiation by means of a quantum counter, such as a Geiger or scintillation counter. The latter instrumentation is the better of the two for the study of liquids and solutions because one can get better curve fitting and, thus, better peak resolution in the radial distribution curve.

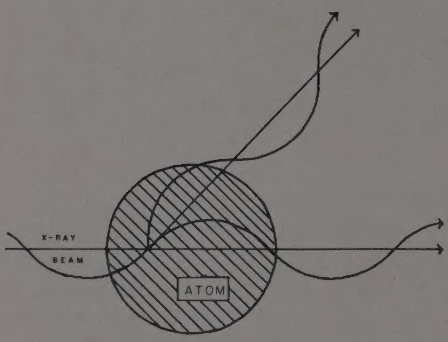
Diffracting Power of Atoms

When an atom is exposed to electromagnetic radiation, the electrons are accelerated, and they radiate at the frequency of the incident radiation. At optical frequencies the superposition of the waves scattered by individual atoms results in ordinary optical refraction. When x-rays strike an atom they are diffracted by the cloud of electrons forming the outer part of the atom. A schematic representation of the scattering of x-rays by atoms is given in figure 1. The diffracting power of an atom is determined by the number of electrons in the atom. Atoms such as iodine and lead, which have high atomic numbers, are higher in diffracting power than atoms such as carbon and oxygen, which have low atomic numbers. Therefore, in studying any material one can expect better diffraction patterns from large atoms than from small ones. If one is working with liquids or solutions in which there is short-range order, the choice of a system with large atoms, or at least some large atoms, will result in a better diffraction pattern than would be obtained from a system composed of only small atoms.

Periodic Repetition of Atoms

A pure chemical substance has the fundamental feature that all of its atoms or molecules are duplicates of all other atoms or molecules in the substance. From the viewpoint of geometry each atom or molecule is a copy of some arbitrarily selected reference atom or molecule of the mass. When this reference unit is repeated systematically, a periodic pattern exists. In nature this periodic repetition is found in one, two, or three dimensions. A systematic study of repetitive patterns shows that there are two types of purely one-dimensional patterns, 17 types of purely two-dimensional patterns, and 230 types of purely three-dimensional patterns.

The crystalline solid with its periodic repetition in three dimensions reveals its structure very easily through the use of x-ray. The x-rays, whose wavelength is comparable to the lattice spacing of the atoms in a crystal, will be diffracted under certain conditions. W. L. Bragg explained the characteristics of the diffracted beam by a simple model in which he assumed that the x-rays are reflected from the atoms which are periodically arranged in the crystal. The diffracted beam is found only in those special situations where the reflections from atoms arranged



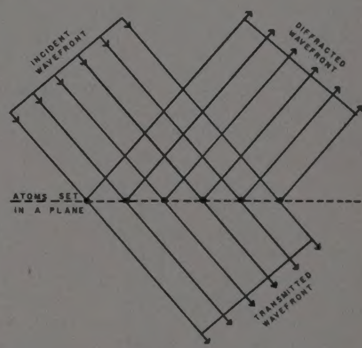


FIGURE 1. (Left) Scattering of x-rays by an atom.
FIGURE 2. (Right) Schematic diagram to show reflection and transmission of x-rays by atoms set in a plane.

in parallel planes interfere constructively. If a train of x-rays whose wave front is perpendicular to the direction of propagation is scattered by an array of atoms, the scattered x-rays interfere with each other except when they are in phase, i.e., when the difference between the wavelength of the scattered rays by different atoms is zero or a whole number of wavelengths.

Because of the great penetrating power of x-rays, a single atom cannot reflect a large fraction of the incident x-rays; many of the rays are transmitted through a single atom. This statement can be illustrated schematically as shown in figure 2. As can be seen in this diagram, the distance from the original wave front to an atom and on to a new wave front is the same for all atomic locations for the atoms set in a given plane. The directions of the wave fronts are either a continuation of the beam (transmitted beam) or a reflection of the beam (diffracted beam). In order to get the resultant reflection, the partial reflection from many atoms, periodically arranged, must be added. In order for these reflections to be constructive, each reflecting layer of atoms must be an integral number of wavelengths longer than the one immediately above it. This is illustrated in figure 3, where A′B′C′ is an integral number of wavelengths longer than ABC and, therefore,

constructive interference of x-rays results. The difference in the lengths of the paths followed by these two rays is nλ.

So much for the crystalline solid which, by its periodic arrangement of atoms, gives a series of sharp rings in its diffraction pattern. A diffraction pattern of sodium chloride crystals is shown in figure 4(A).

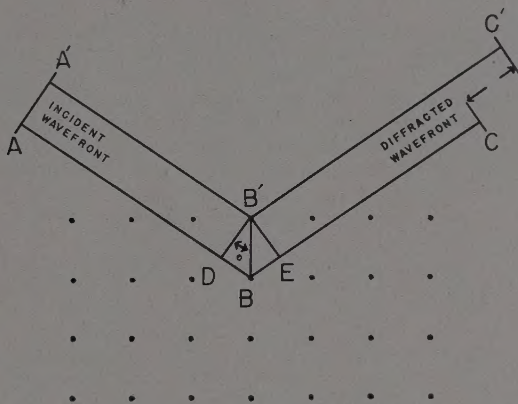


FIGURE 3. Illustration of constructive reflections of x-rays from periodic arrangement of atoms.

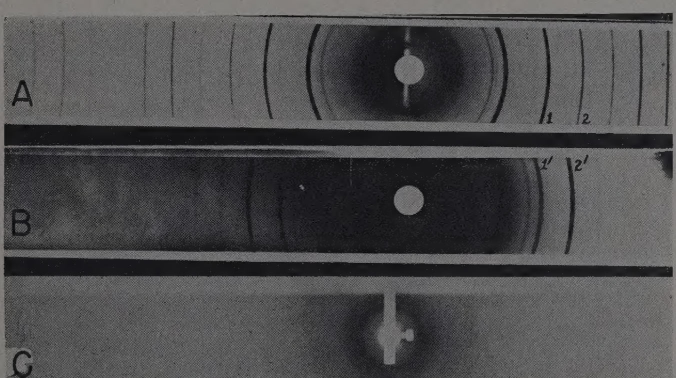


FIGURE 4. Diffraction patterns of A, sodium chloride; B, metallic sodium in a propylene polymer; and C, a 12.4 molal solution of lithium iodide in water. Note the change in the breadth of the rings (1 and 1′, 2 and 2′) as the particle size decreases.

Non-Crystalline Materials

There is no sharp dividing line between crystalline and non-crystalline materials. With decreasing crystallite size, the widths of the lines composing the powder pattern of a solid increase, and the stronger lines in the pattern assume a diffuse design characteristic of non-crystalline materials. This kind of pattern is illustrated in figure 4(B), where a dispersion of metallic sodium in a propylene polymer is shown. Ring broadening takes place when the crystallite size falls below ap-

proximately 10^{-5} cm. This effect is analogous to the imperfect resolution of an optical grating containing only a few lines. As the particle size of the crystallite becomes increasingly smaller, the x-ray reflections become increasingly diffuse until at the limit of 10^{-7} to 10^{-8} cm, which is the region of atomic dimensions, a precise, repetitive pattern ceases to exist. The repetitive order found in liquids is obviously somewhere between that of the solid and the region of atomic dimensions.

The x-ray diffraction pattern of a liquid or a solution consists of diffuse halos, usually no more than two or three in number. This kind of pattern shows that the molecules of a liquid have short-range order. Beyond two or three molecular diameters the structure in one part of the liquid has no effect on that in another part. However, the existence of halos in the x-ray pattern shows that there is some short-range order in the liquid and solution to give a "smeared-out" ring. A diffraction pattern of a 12 molal solution of lithium iodide in water is shown in

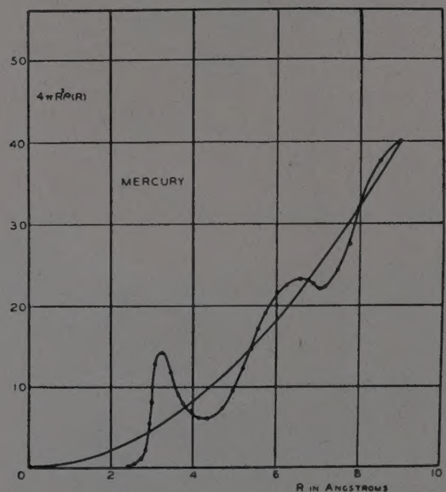


FIGURE 5. Radial distribution curve for mercury. (Reproduced with permission from Gingrich, N. S. 1943. Revs. Modern Phys. 15: 106).

figure 4(C). The marked difference between this pattern and that of a crystalline solid is obvious. It can be seen that a crystalline material gives a rich diffraction pattern with an orderly arrangement of a large number of images in the three dimensions of reciprocal space. These patterns can be used to obtain accurate data on the arrangement of atoms. The diffuse patterns from non-crystalline materials, liquids, and solutions reflect only the statistical approximate order in these systems. These patterns can likewise be interpreted to obtain an arrangement of atoms in the structure.

As one studies the diffraction pattern of a non-crystalline material, he finds that the possibilities of interpretation become more restrictive than in solids. However, there are two ways that one can proceed to interpret the x-ray diffraction patterns of liquids and solutions. First, one can postulate particular arrangements of atoms, the intensity patterns at different angles can be calculated, and these calculated values compared with the actual diffraction pattern of the specimen.

Another method, and the one described herein, is to convert the experimental diffraction pattern by the Fourier Series method into a vector diagram. If there is only one type of atom present in the species, this diagram will represent the radial distribution of atoms around any particular atom in the specimen. If there is more than one type of atom present, all the vectors in the specimen are superposed in all directions; the vector diagram must be interpreted in terms of atomic arrangements.

To understand the radial distribution function, let us suppose that we pick a molecule (considered as a point) at random in the liquid and draw a series of spheres around it with their volumes regularly increasing. These spheres shall be drawn so that the volume interval between two neighboring spheres is always the same. The radial-distribution function is then the average of the number of atoms or electrons between such neighboring spheres as a function of the radial distance from the central atom or electron. In other words, the distribution function is a measure of the average density of the liquid as a function of intermolecular distance.

As expected, the function is zero at very small distances since atoms and molecules occupy a finite space and cannot be closer together than their diameters. The value of the radial distribution function jumps to a high maximum at the distance of nearest neighbors to the reference molecule; it falls off and then peaks again less sharply for the next nearest neighbors; and it peaks still less sharply for the third nearest neighbors. Eventually the function smears out to a uniform value. The radial distribution curve of mercury as determined by Gingrich (1943) is given in figure 5. The curve gives the average distribution of neighboring atoms (electron density) as a function of the distance from the center of a reference mercury atom. Also, from the radial distribution curve one gets directly the concentration of atoms at distances from a given atom and, since the work is quantitative, the areas under the peaks give directly the number of atoms in that range of distances.

Structure of Water and Formamide

The x-ray structure of water was first worked out by Morgan and Warren (1938) and the results of their study are shown in figure 6. The first peak in this curve, which represents the distance between closest neighbors, is at 2.90 Å at a temperature of 1.5°C and at 3.05 Å at a temperature of 83°C. This peak represents the distance between oxygen atoms in neighboring water molecules and compares favorably with the value of 2.76 Å in ice. The intermolecular distance in water is, therefore, slightly greater than in ice and increases with temperature. The area under the first peak in the radial distribution curve gives a value of approximately four nearest neighbors. At the temperatures of 1.5°, 13° and 30°C, a marked concentration of neighbors at a distance of approximately 4.5 Å is clearly indicated on the distribution curve.

From the value of the distance between the nearest neighbors, the number of nearest neighbors, and the presence of neighbors at a distance of 4.5 Å, the structure of water can be established. As one sets out to establish the structure of water, one of the logical structures that might come to mind at first is a close-packed arrangement of the molecules. In the close-packed arrangement one would expect to find a number of nearest neighbors approximately equal to twelve (assume the molecules are essentially spherical). From the experimental data of Morgan and Warren, it is clear that water does not even approximate a close-packed liquid. Another line of reasoning one might follow in arriving at the structure of water is to relate the structure of water to that of ice. Figure 7 gives a diagrammatic representation of the structure of ice. It can be seen from this diagram that, in ice, each water molecule is surrounded by four neighboring molecules in tetrachedral arrangement. From the value of the distance between

closest neighbors, the number of nearest neighbors, and the broad peak at 4.5 Å, all obtained from the radial distribution curve, it is evident that the water structure approximates that of ice. The disappearance of the peak at 4.5 Å as the temperature rises indicates that the tetrahedral bonding in water becomes less sharply defined or less prevalent. Therefore, in a brief summary of the work of Morgan and Warren, one can say that x-ray results show an essentially tetrahedral structure for water, but that this structure cannot be interpreted uniquely in terms of a definite number of neighbors at a certain distance. The structure undoubtedly involves a continual change in neighbors in the tetrahedral unit. The structure of water has been verified by other workers (Brady and Romanow, 1960; Strauss, 1960).

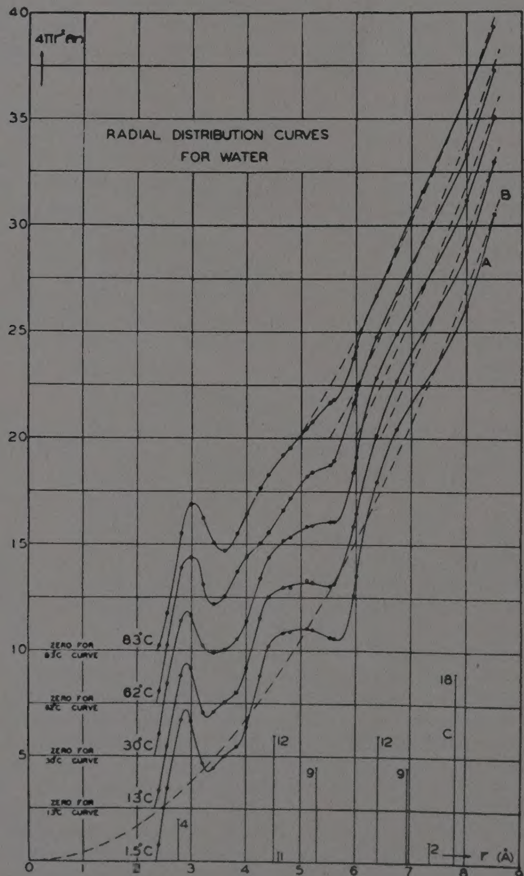


FIGURE 6. Radial distribution curves for water for various temperatures. (Reproduced with permission from Morgan, J. and B. E. Warren. 1938. J. Chem. Phys. 6: 670).

The structure of the formamide molecule was worked out by Costain and Dowling (1960) using microwave spectroscopy. A picture of their structure of the molecule is given in figure 8. Costain and Dowling concluded that the H_2N—C group forms a shallow pyramid while the N'—CHO group is planar. The dihedral angle between the H'NC plane and the NCO plane is $7° \pm 5°$ and between the H'' NC plane and the NCH plane is $12° \pm 5°$. The C—N distance in the moleclue is 1.38 Å. X-ray methods are not very definitive in unraveling the structure of formamide. The radial distribution curve in figure 9 shows a peak at 4.0 Å and one at 4.9 Å. The 4.0 Å distance is the combination of atomic distances across the formamide dimer, i.e., carbon-carbon, oxygen-oxygen, nitrogen-nitrogen, etc.

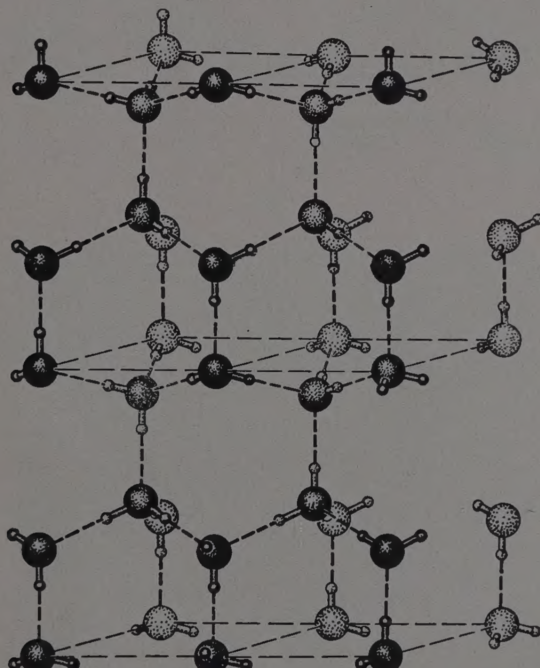


FIGURE 7. Diagrammatic representation of the structure of ice. (Reproduced with permission from Pauling, L. 1960. The Nature of the Chemical Bond. Cornell University Press. 465 pp.).

distance, while the 4.9 Å distance is most likely the distance between dimers. The peak at approximately 1.5 Å indicates the presence of the C—N bond. The complete analysis of the x-ray structure of formamide will be published elsewhere.

Before leaving the consideration of pure liquids, I should call attention to a recent proposal by Bernal (1959) on the geometry of liquids. He has proposed that liquids show fivefold axial symmetry which is quite in contrast with solids which can have only twofold, threefold, fourfold, or sixfold axial symmetry. An arrangement of fivefold symmetry in a two-dimensional pattern, representing Bernal's ideas, is shown in figure 10. Alongside this pattern is one representing sixfold symmetry which leads to a two-dimensional hexagonal pattern. The

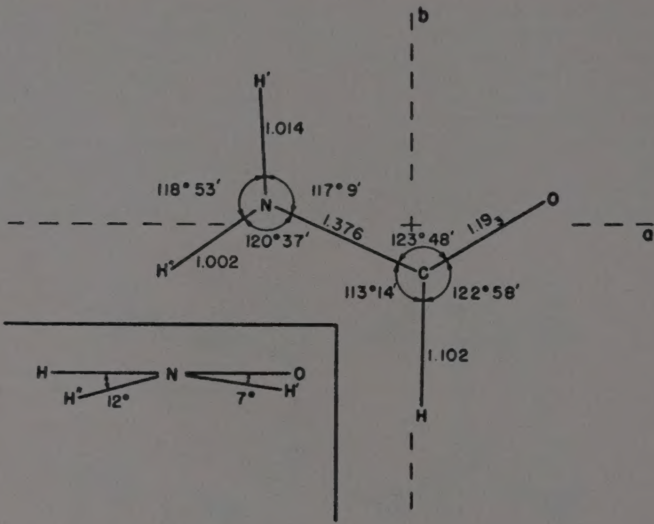


FIGURE 8. Probable structure for the formamide molecule. Insert shows molecule viewed along N—C bond with the N—CHO plane perpendicular to the plane of the drawing. (Reproduced with permission from Costain, C. C. and J. M. Dowling. 1960. J. Chem. Phys. 32: 165).

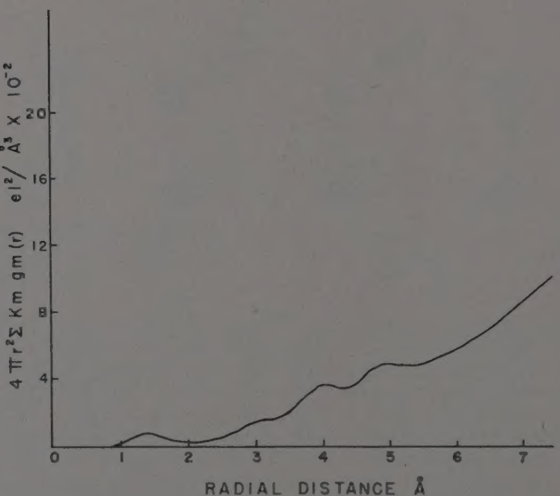


FIGURE 9. Radial distribution curve for formamide.

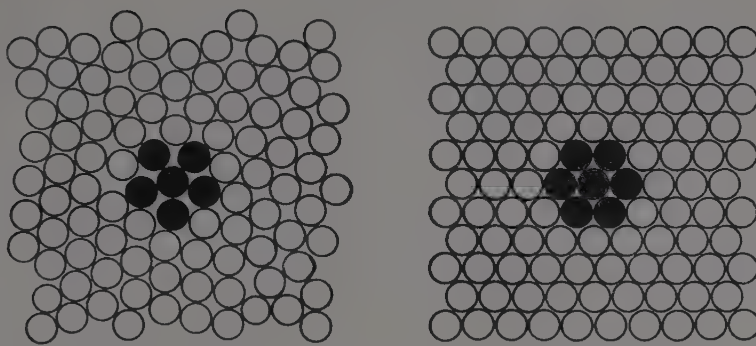


FIGURE 10. Figure on left represents fivefold symmetry in two dimensions. Figure on right represents sixfold symmetry in two dimensions. (Reproduced by permission from Bernal, J. D. 1960. Sci. Am. 203: 130).

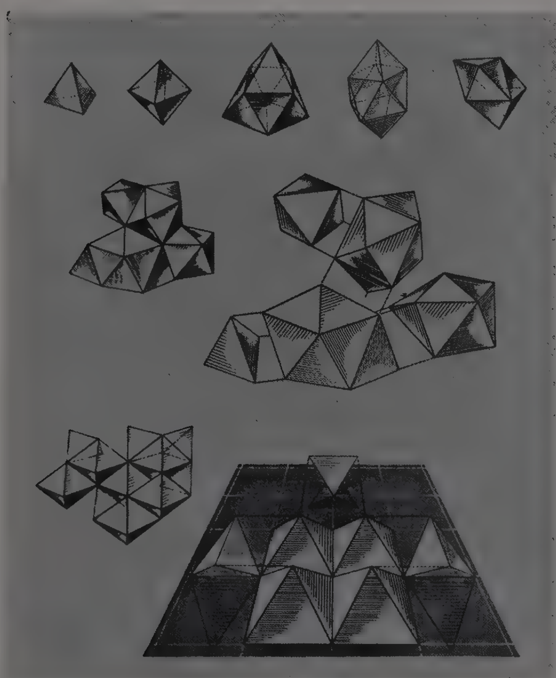


FIGURE 11. Diagram representing polyhedral "holes" in liquid structure. From left to right at the top are: regular tetrahedron, regular octahedron, and three semi-regular solids with 14, 16, and 12 faces, resp. (Reproduced with permission from Bernal, J. D. 1960. Sci. Am. 203: 124).

first of these patterns shows irregularity over an extended area while the second shows regularity. Bernal concludes that the fivefold axial symmetry which gives irregularity over an extended volume is the basic structure of liquids.

If one takes a reference point in a liquid that is not a molecule and surrounds this point with molecules, the positions of these molecules may be thought of as defining a hole in the shape of a polyhedron (formed if the centers of the atoms are connected with straight lines). Furthermore, if one considers relatively dense packing and an ideal structure in which all the molecules are the same distance apart, mention need be made only of the polyhedra with equal edges, namely, the tetrahedron, octahedron, and three semiregular figures (see upper portion of figure 11). If these polyhedra represent the geometry of "holes" in a liquid, then these polyhedra may be used to build the structure of a liquid. In the middle and lower portions of figure 11 there are two possible patterns of arrangements. The arrangements in each case are nested at the left and exploded at the right. The lower pattern is composed only of tetrahedra and octahedra in the ratio of two to one and shows regular arrangement which results in a repeating pattern. The upper pattern is a typical irregular pattern composed of one each of the different polyhedra represented at the top of the figure. This pattern, if extended, would not give a repeating arrangement. Thus, using Bernal's ideas, this sort of an arrangement results in an example of a possible network of "holes" to form a liquid structure.

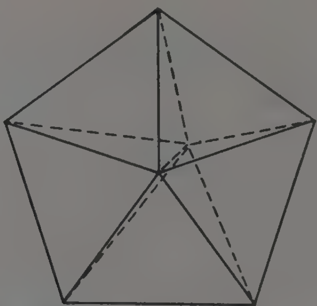


FIGURE 12. Model of the packing of five tetrahedral "holes" sharing a common edge. This pattern shows fivefold symmetry.

There are a large number of arrangements of "holes" that might correspond to the short-range order of a liquid. Assuming the tetrahedra represent "holes" in the liquid around which molecular spacings take place, another likely arrangement is the packing of the five tetrahedra in such a fashion that they have an edge in common. This arrangement, shown in figure 12, gives a cross-sectional view in which are seen five molecules arranged at the apices of the tetrahedra. Such a pattern shows fivefold axial symmetry and cannot grow indefinitely since it closes in on itself.

This brief resumé of Bernal's geometry of liquids cannot do justice to a very interesting idea. The interested reader is referred to the original paper (Bernal, 1959).

Structure of Solutions

A number of measured properties of solutions, such as conductance and viscosity, show abnormal behavior in the concentrated regions. For example, it has been known for some time that the electrical conductance of most 1:1

electrolytes in water rises as the concentration of the solute rises, passes through a maximum, and then decreases. Theoretically one would expect the conductance to increase as the concentration of solute increases. X-ray structure studies of solutions show that this decrease in conductance can be attributed to ionic aggregates in the system. Several of these studies will be cited in the paragraphs which follow.

I shall consider first two different solutions which have been studied in my research. A detailed report on the complete analysis and interpretation of the structure of these two solutions, along with others of the same solutes at different concentrations, will be published elsewhere. The first of these solutions is a 12.4 molal solution of lithium iodide in water. The radial distribution curve for this system is shown in figure 13. This curve has been corrected for the contribution of water. The peaks below 2 Å are considered to result from spurious effects, characteristic of Fourier inversion and are, therefore, not significant in the analysis of the structure. The first important peak is the one at 3.7 Å, which represents

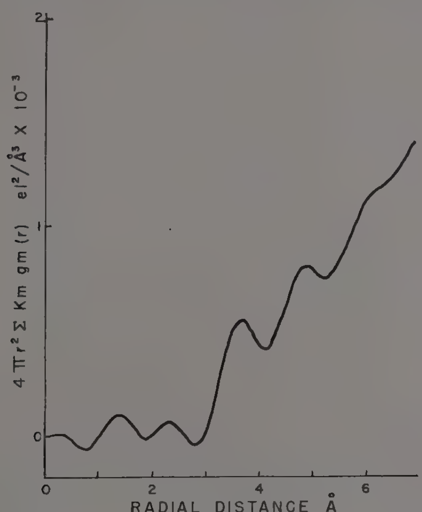


FIGURE 13. Radial distribution curve for a 12.4 molal solution of lithium iodide in water.

an iodide ion-water interaction while the peak at 4.95 Å represents an iodide ion-iodide ion interaction. The area under the first peak is 7.9 and under the second peak it is approximately two. The details by which one arrives at these peak assignments and areas will be described elsewhere, and for the present consideration it will be sufficient to accept the assignments. With these peak assignments and the areas under the peaks, one must set out to assign a structure to the system using any available information at one's disposal. The first logical information to seek is whether the structure of crystalline lithium iodide trihydrate has been determined. Fortunately, the structure of the crystal has been worked out by West (1934), who proposed a hexagonal symmetry. It will be remembered that from the radial distribution curve is obtained the distance of nearest neighbors, next nearest neighbors, second nearest neighbors, and, from areas under the peaks, the number of atoms in that range of distances. If one has this knowledge of the crystalline structure of lithium iodide trihydrate and uses the data from the

radial distribution curve, he can construct a model of the ionic aggregate such as that shown in figure 14. In this structure there is a centrally located lithium ion surrounded by six molecules of water at a distance of 2.4 Å and six iodide ions at a distance of 4.5 Å. The lithium ion, water molecule, and iodide ion are represented in figure 14 by an increase in the diameter of the circle, respectively. It should be noted that the lithium ion is not only in the center of a regular octahedron whose apical positions are occupied by water molecules, but it is also located in the center of a flattened octahedron formed by iodide ions.

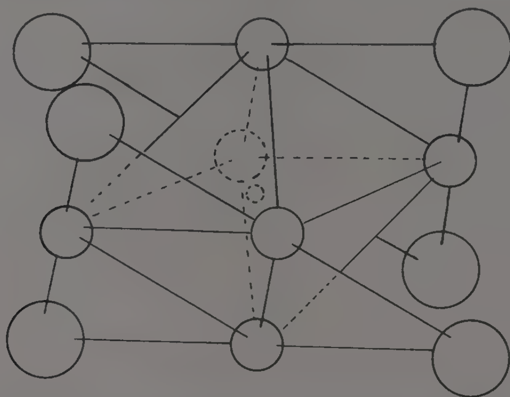


FIGURE 14. Proposed model of the aggregate of lithium and iodide ions and water molecules in a 12.4 molal solution of lithium iodide. Lithium ion is represented by smallest circle, water by next smallest, and iodide ion by the largest circle.

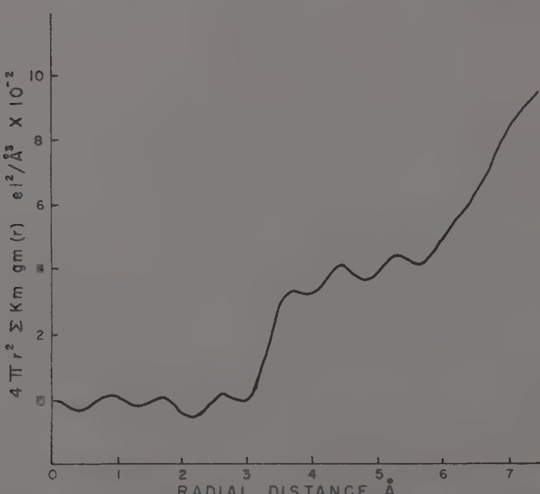
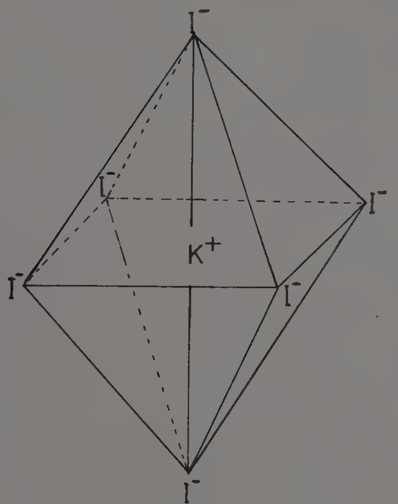


FIGURE 15. Radial distribution curve for a 4.02 molal solution of potasssium iodide in formamide.

The aggregate shown in figure 14 can be extended in all directions to accomodate twenty-one extra molecules of water and additional lithium ions to preserve electrical neutrality in the "lattice" of the 12.4 molal solution. Therefore, the structure sketched in figure 14 represents the predominate species in the aqueous solution of 12.4 molal lithium iodide.

Next, let us consider a solution of potassium iodide in formamide. Formamide has a large dielectric constant (109 at 20°C) compared to water with a value of 78.5 at 25°C. Because of the large dielectric constant of formamide, one might expect less association of ions in this solvent than in water. Let us look at the radial distribution curve for a 4.02 molal solution of potassium iodide in formamide to see what kind of ion aggregate, if any, exists in such a solution. Figure 15 represents the radial distribution curve of such a solution.



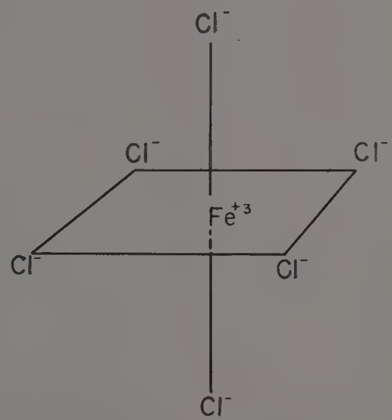


FIGURE 16. (Left) Proposed model of the aggregate of potassium and iodide ions in a 4.02 molal solution of potassium iodide in formamide.
FIGURE 17. (Right) Proposed model of the aggregate of iron (III) and chloride ions in a concentrated solution of iron(III) chloride.

The two peaks I wish to consider first in this curve are at 3.70 Å and 5.25 Å. The first of these distances is a potassium ion—iodide ion interaction and the second an iodide ion—iodide ion interaction. Using these distances and what one knows about comparable distances in crystalline potassium iodide, one can construct a model like that in figure 16. The area under the potassium ion—iodide ion peak gives a coordination number of 6.7. The model proposed in figure 16 fits the nearest and next nearest neighbor spacings quite well, i.e., potassium ion—idodide ion distance and iodide ion—iodide ion distance. The structural unit in this solution is a $K_5I_6^{-1}$ anion and electrical neutrality is obtained by a potassium cation. A likely location for four of the potassium ions is in four of the faces of the octahedral structure for the KI_6^{-5} unit (fig. 16). The peak at 4.4 Å represents a potassium ion—iodide ion distance, with the potassium ion on the negative end of the formamide dipole and the idodide ion on the positive end of the same dipole. Details of the interpretation of the structure of the 4.02 molal solution of potassium iodide in formamide and of other solutions of the same salt in formamide will be published later.

A few studies of solutions by other research workers will be cited. Brady (1958a) has interpreted the structure of solutions of lithium chloride (0.11 LiCl:0.89 H_2O) in water. He based his structure on a tetrahedrally arranged sphere of water molecules coordinated to a centrally located lithium ion. He then postulated that some of the molecules of water in the sphere of hydration around the lithium ion are shared by two chloride ions per water molecule. This assignment of locations of chloride ions results in two distances representing chloride ion—chloride ion interaction, i.e., a distance between two chloride ions

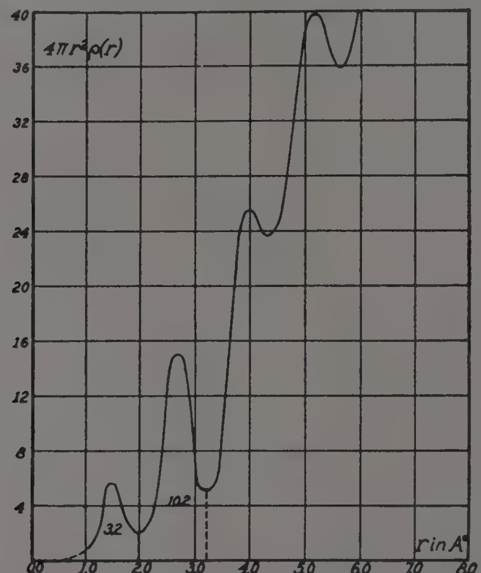


FIGURE 18. Radial distribution curve for carbon black. (Reproduced with permission from Warren, B. E. 1934. J. Chem. Phys. 2: 553).

TABLE 1

Number of neighbors and distances in a single graphite layer (Warren, 1934)

Average Distance (Å)	Distance (Å)	Number of Neighbors
	1.42	3
2.6	2.46	6
	2.84	3
4.0	3.75	6
	4.25	6
5.0	4.92	6
	5.11	6

sharing the same molecule of water located at the apices of the tetrahedron and a distance between chloride ions which are associated with two different molecules of water located at two different apices of the same tetrahedron.

In solutions of iron(III) chloride in water Brady (1958b) found that as the concentration of iron(III) chloride increases, the extent of higher order complexing increases and in a nearly saturated solution, the octahedral ion, $(FeCl_6)^{-3}$, is the predominant form present. This ion is shown in figure 17.

Other Applications of X-ray Analysis of Non-Crystalline Materials

A number of studies of non-crystalline materials, other than those already cited, have been made; only a few will be mentioned here. The structure of carbon black was worked out a number of years ago by Warren (1934). The radial distribution curve shown in figure 18 agrees with the existence of single graphite layers. The data from Warren are summarized in table 1.

Figure 19 shows the arrangement of neighbors about a reference atom in a single graphite layer. The circles in the background on the drawing outline the number of neighbors and the distances from the reference atom starting at 1.42 Å and going to a 5.11 Å distance.

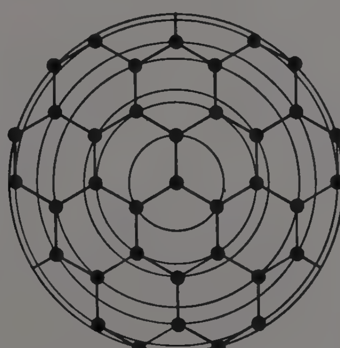


FIGURE 19. Arrangement of neighbors about a reference atom in a single graphite layer. (Reproduced with permission from Warren, B. E. 1934. J. Chem. Phys. 2: 554).

From this study of carbon black it is clear that it is not a truly amorphous form of carbon. The existence of single layers of graphite is clearly established, and the diffraction data indicate a heterogeneous mixture containing particles which range from single graphite layers to graphite crystals of larger size.

I shall mention one more interesting study of a non-crystalline material. Klug and Alexander (1954) report a study of the structure of polyisoprene. The isoprene unit has a stoichiometric composition of C_5H_8 and has the name, 2-methyl-1,3-butadiene. The radial distribution curve for this non-crystalline system is given in figure 20. The first peak indicates two nearest neighbors at about 1.5 Å, and the second peak shows approximately three second neighbors at 2.55 Å. The positions and areas of the first two peaks in the polyisoprene curve show that the polysiosprene structure consists of coiled or folded long-chain methyl-1,3-butadiene. The radial distribution curve for this non-crystalline of 109° and a single-double bond angle of approximately 125°. The data, however, do not allow one to make a definite choice between the several possible ways in which addition takes place in the polymerization of the isoprene.

Figure 21 shows the relationship between the radial distribution curves of

polyisoprene and natural rubber. It is clear that the structures of polyisoprene and natural rubber are very much alike. The first two peaks are very similiar while the indefiniteness of the third peak results from rotational freedom about the single bond in the polymer. This structural relationship between polyisoprene and natural rubber is one of the most convincing evidences in our knowledge that natural rubber has isoprene as its building unit.

The examples of the radial distribution procedure cited in this paper point up its importance. The method yields itself to many other uses such as structure of polymers, of molten salts, of elements such as sulfur when melted, and of molten alloys.

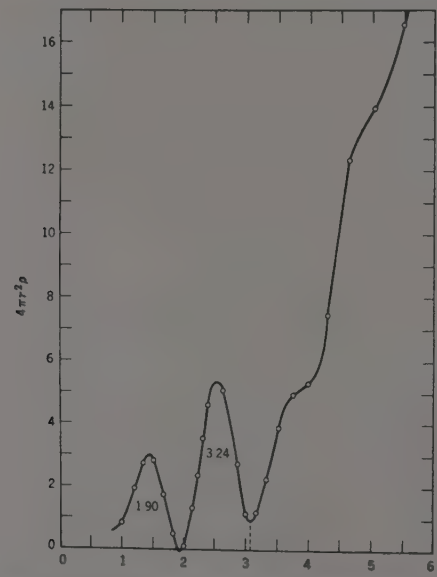


FIGURE 20. Radial distribution function of synthetic polyisoprene. (Reproduced with permission from Klug, H. P. and L. E. Alexander. 1954. X-Ray Diffraction Procedures. John Wiley & Sons, Inc. 716 pp.).

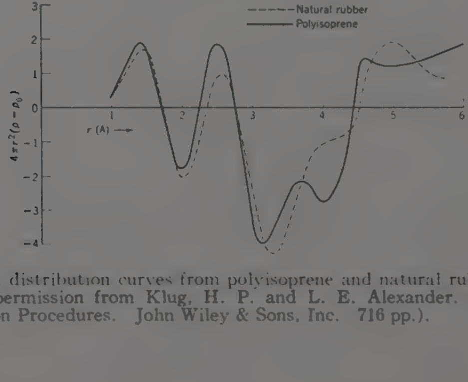


FIGURE 21. Radial distribution curves from polyisoprene and natural rubber. (Reproduced with permission from Klug, H. P. and L. E. Alexander. 1954. X-Ray Diffraction Procedures. John Wiley & Sons, Inc. 716 pp.).

In this brief review of the structure of liquids and solutions I have attempted to acquaint you with the end results of the x-ray method without burdening you with the theory involved. Adequate references have been given to guide an interested person into a deeper understanding of the subject. It is safe to say that the studies of the structures of liquids and solutions will result in some interesting new developments in the future. Workers have only begun to look into the mysteries of the structures of these systems.

REFERENCES

Bastiansen, O. and **C. Finbak.** 1944. Structure of liquids. IX. Aqueous solutions of phosphoric acid. Tidsskr. Kjemi Bergvesen Metal. 4: 40.

Bernal, J. D. 1959. A geometrical approach to the structure of liquids. Nature. 183: 141.

———. 1960. The structure of liquids. Sci. Am. 203: 125.

——— and **R. H. Fowler.** 1933. A theory of water and ionic solution, with particular reference to hydrogen and hydroxyl ions. J. Chem. Phys. 1: 515.

Born, M. and **S. Green.** 1946. A general kinetic theory of liquids. I. The molecular distribution functions. Proc. Roy. Soc. Lon. (A)188: 10.

Brady, G. W. 1958a. Structure of ionic solutions. II. J. Chem. Phys. 28: 464.

———. 1958b. Structure of Ionic Solutions. III. J. Chem. Phys. 29: 1371.

——— and **J. T. Krause.** 1957. Structure of ionic solutions. I. J. Chem. Phys. 27: 304.

——— and **W. G. Romanow.** 1960. Structure of water. J. Chem. Phys. 32: 306.

Costain, C. C. and **J. M. Dowling.** 1960. Microwave spectrum and molecular structure of formamide. J. Chem. Phys. 32: 158.

Debye, P. and **E. Hückel.** 1923a. The theory of elcectrolytes. I. Lowering of freezing point and related phenomena. Physikal. Zeitschr. 24: 185.

——— and ———. 1923b. Theory of electrolytes. II. The limiting law of electrical conductivity. Physikal. Zeitschr. 24: 305.

Devik, O., C. Finbak, and **O. Ronning.** 1944. Structure of liquids. X. Sodium hydroxide dissolved in water. Tidsskr. Kjemi Bergvesen Metal. 4: 50.

Eyring, H. 1936. Viscosity, plasticity, and diffusion as examples of absolute reaction rates. J. Chem. Phys. 4: 283.

——— and **J. Hirschfelder.** 1937. The theory of the liquid state. J. Phys. Chem. 41: 249.

Finbak, C. and **O. Bastiansen.** 1943. Structure of solutions. V. Hydrochloric acid dissolved in water. Tidsskr. Kjemi Bergvesen Metal. 3: 98.

Frenkel, J. 1946. Kinetic Theory of Liquids. Oxford University Press. 499 pp.

Furth, R. 1941. The theory of the liquid state. Proc. Cambridge Philos. Soc. 37: 252–290.

———, **L. S. Ornstein,** and **J. N. W. Milatz.** 1939. Theory of liquids. Proc. Acad. Sci. Amsterdam 42: 107.

Gingrich, N. S. 1943. The diffraction of x-rays by liquid elements. Revs. Modern Phys. 15: 90.

Kirkwood, J. G. 1935. Statistical mechanics of fluid mixtures. J. Chem. Phys. 3: 300.

———. 1939. Molecular distribution in liquids. J. Chem. Phys. 7: 919.

———. 1946. The statistical mechanical theory of transport processes. J. Chem. Phys. 14: 180.

Klug, H. P. and **L. E. Alexander.** 1954. X-ray Diffraction Procedures. John Wiley & Sons, Inc. 716 pp.

Lennard-Jones, J. E. and **A. F. Devonshire.** 1937. Critical phenomena in gases. I. Proc. Roy. Soc. London (A) 163: 53.

——— and ———. 1938. Critical phenomena in gases. II. Vapor pressures and boiling Points. Proc. Roy. Soc. London (A) 165: 1.

Mayer, J. E. 1950. The theory of ionic solutions. J. Chem. Phys. 18: 1426.

Morgan, J. and **B. E. Warren.** 1938. X-ray analysis of the structure of water. J. Chem. Phys. 6: 666.

Pauling, L. 1960. The Nature of the Chemical Bond. Cornell University Press. 465 pp.

Prins, J. A. 1935. Molecular arrangement and x-ray diffraction in ionic solutions. J. Chem. Phys. 7: 869.

——— and **H. Peterson.** 1936. Theoretical diffraction patterns corresponding to some simple types of molecular arrangements in liquids. Physica 3: 147.

Stewart, G. W. 1930. X-ray diffraction in liquids. Revs. Modern Phys. 2: 116.

———. 1939. The variation in structure of water in ionic solutions. J. Chem. Phys. 7: 869.

Strauss, M. 1960. X-ray diffraction studies of some aqueous solutions of lithium iodide. Doctoral Dissertation. University of Cincinnati. (Dissertation written under the direction of G. H. Brown.)

Thewlis, J. 1950. Neutron crystallography. Ann. Rept. Chem. Soc. 47: 420.

Warren, B. E. 1934. X-ray diffraction study of carbon black. J. Chem. Phys. 2: 551.

West, C. D. 1934. Crystal structures of some hydrated compounds. Zeitschr. Kristallog. 88: 198.

BEHAVIOURAL EFFECTS OF TEMPERATURE ON INSECTS

MOHAMMAD ABDULLAH
Department of Entomology, University of Illinois

Like the propagation of light rays, radiation of heat occurs in straight rays consisting of waves. The wave length and the amount of energy determine the intensity of heat or temperature, which is readily measurable. Heat is due to infra rays ranging from 0.1 mm to 770 mμ and decreases towards the visible spectrum. Temperature is a physical factor as well as a stimulus for insects. It can be a token stimulus or a sign for some other thing as in the case of insect parasites of vertebrates.

Life is limited within a range of temperature at the limits of which survival depends upon certain physiological adaptations in poikilothermic animals, such as selection of preferred temperature, variation in water distribution, regulation of water loss, and other metabolic reactions including suspension of active life processes at unfavourable temperatures (Prosser, 1952). Heat may be lost by radiation, convection, conduction, vaporization of water, and circulation of heat from interior to surface, while gain of heat occurs by absorption of heat largely from the solar radiation, besides oxidative and other metabolic means.

COLD AND HEAT RECEPTORS

The mechanism of temperature perception is not known and there is no indication of an "intermediate substance" being involved between the sensory receptor cell and the heat waves. Anatomically the temperature sense organs are simple sensory cells and are usually localized by observation of the reactions of insects to temperature and the way their behaviour modifies on amputation of various parts of insect body. Temperature receptors can now be studied electrophysiologically (table 1).

Wigglesworth and Gillett (1934) suspect their type iii sensilla on upper two third area of the first flagellar segment and entire second (=last) flagellar segment as the heat receptors since they are the most numerous in distribution. They are fine, curved, small, slender structures ending in a sharp point. Histologically the sensillum is thick-walled, with a very small central cavity and a small gland cell having five or six nerve cells. Slifer (1951, 1953) has found that the males of the African migratory locust have the largest heat sensitive areas on fourth, fifth, and sixth abdominal terga and suggests that these may serve to protect the spermatozoa from excessive heat, because they are located just above the gonads. Similarly fenestrae may be used by the female in finding a suitable temperature for oviposition.

Not much work has been done on the electrophysiology of temperature receptors. Hodgson and Roeder (1956) showed a positive temperature effect for the sensory discharges of taste-receptors in *Phormia*. Kerkut et al. (1957) for the first time found evidence for cold receptors in insects by studying the electrical responses of the isolated limb of the American cockroach following localized warming and cooling. The receptors are sensitive to 1° C drop in temperature of the substratum with which the feet of the cockroach are in contact over the critical range below 13° C, but are less sensitive to a rise of temperature, being stimulated by 5° C rise. This is like the increased activity of cold receptors in cat's tongue at low temperature (Dodt et al., 1952).

Thermoreception occurs by lateral line organs in fishes (Rubin, 1935), ampullae of Lorenzini in elasmobranchs (Sand, 1938), dermal receptors in general (Dijkgraaf, 1943; Hesse, 1924), heat and cold dermal receptors in frog (Morgan, 1922), sensory pits in pit vipers and head of certain boas (Noble et al., 1937), Ruffini organs which lie deeper in integument and the cold receptors, bulbs of Krouse located peripherally in man (Bazett, 1941; Bazett et al., 1930).

EFFECT OF RADIATION ON BODY TEMPERATURE

Insects in general are poikilotherms, but some of them exhibit a limited degree of heterothermy by maintaining their body temperature a little higher or lower than that of their environment. Examples are *Vanessa* butterfly and certain lamellicorn beetles that "warm up" before "take off" in air (Dotterweich, 1928; Krogh et al., 1941; and Oosthuizen, 1939); honeybees during summer and winter periods decrease and increase the colony temperature accordingly (Himmer, 1932 and Pirsch, 1923); the grasshopper, *Oedipoda coerulescens*, gets warmer than air shortly after sunset (Franz, 1930); and *Schistocerca gregaria* has its body temperature fluctuating between 40° and 45° C during the day, a little higher than the air (Bodenheimer, 1930).

TABLE 1
Cold and heat receptors

Arthropod	Location of sense organs	Remarks	Reference
Crickets	antennae, cerci and mouth parts, tarsi		Herter, 1923
Blabera fusca	labial palps, tarsi	by hot needle	Herter, 1924
Liogryllus campestris	antennae, labial palp, tarsi, cerci	same	Herter, 1924
Melanoplus differentialis, M. femur-rubrum and *Disossteria carolina*	antennae, pulvilli, tarsi, dorsal and ventral sides of abdomen and palps	increasing order of sensitivity	Geist, 1928
Collembola	antennae		Strebel, 1932
Menexenus semiarmatus	12th antennal segment, dorsal surface	by ampuattion	Cappe de Baillon, 1932
Rhodnius prolixus	1st and 2nd flagellar segments of antenna	type iii in their fig.	Wigglesworth et al., 1934
Carausius morosus	14th antennal segment	by amputation	Herter, 1939
Ixodes reduvius	on leg and body surface		Lees, 1948
Dorcus parallelepipideus	three distal antennal segments, maxillary palpi		Gebhardt, 1951 and 1953
Otiorrhynchus ligustici	antennae, tarsi		ibid.
Pyrrhocoris apterus, Lygaeus equestris	antennae		ibid.
Locusta migratoria migratoriodes	antennal crescents and fenestrae	by histology, hot glass rod	Slifer, 1951 and 1953
Periplaneta americana	hairs on tarsi, arolium and pulvilli	cold receptor	Kerkut et al., 1957
Opisthothalmus latimanus	abdomen	for thermo-regulation	Alexander et al., 1958

It is thought that coloration plays some role in the thermal economy of insects (Schröder, 1903), but others like Szilady (1921) and Lengerken (1924–27) maintain that metallic colors in insects, like beetles, serve to reflect heat rays in sunshine. Krüger (1929) showed that the wings considerably reflect heat rays while the general body of the butterfly, *Parnassius apollo* absorbs them. According to Huard et al. (1951) however, the primary function of the wing spots is absorption of heat rays. Of the grasshopper, *Kripa coelevriensis*, the blackish-brown form maintained at a 4 to 5° C higher temperature than the buff-colored forms, when both were equally exposed to the sun (Buxton, 1924). Solar radiation alters the body temperature of the desert locust, *Schistocerca gregaria*, which is regulated by change in posture (Fraenkel, 1929 and 1930). Thus, they show no signs of activity below 17° C, move around at 17 to 20° C, and assume such a posture as to receive maximum solar radiation on their perpendicularly oriented bodies. They move about from 30° C upwards to 40° C, when they orient their posture parallel to the sun's rays, thereby receiving minimum solar radiation.

Animals, like lizards and snakes, also form basking groups with respect to solar radiation with the result that, for instance, certain desert lizards have a cloacal

temperature of 38° C at an air temperature of 13° C (Cowles, 1947). While receiving maximum radiation they expand their chromatophores, but are constricted after an optimum body temperature is attained (Gunn, 1942). The lodgepole needle miner, *Recurvaria milleri*, is prevented from over-heating by the orientation of the needles other than 90° to the sun's rays (Henson et al., 1952).

TEMPERATURE PREFERENDUM

Behavioural regulation of body temperature occurs by selection of preferred temperature in nature as well as in the laboratory in an apparatus with a whole series of temperature gradients, where light, humidity, and internal factors such as hunger and sexual activity are controlled (Fraenkel et al., 1940). The preferred temperature region is known by many names such as vorzugstemperatur, thermal or temperature preferendum, temperature optimum, and eccritic temperature (Herter, 1926, 1932; Bodenheimer et al., 1928; Gunn et al., 1938). Some of these terminologies, however, carry anthropomorphic implications, and this criticism is true not only for this, but for much of the studies in insect behaviour. High temperatures cause a direct metabolic effect on the organism resulting in greater speed of locomotion, and an indirect effect of avoiding reactions by action through the nervous system, which no longer exists under optimal conditions.

Cockroaches and other insects are known to prefer warm places. Whereas, cockroaches are active in night, they exhibit what may be taken as an indication of orthokinetic reaction to temperature during daytime as the speed of running increases in warmer regions until it is brought back into the preferendum (Gunn, 1934). The blowfly, *Lucilia cuprina*, has a peak of 33 percent activity at 20° C, another peak of 6 percent activity at 42° C, and is immobile at 5° C (Nicholson, 1934). Subterranean larvae move vertically in soil, probably with regard to temperature, e.g., larvae of *Polyphylla oliveri* (Prinz, 1928) and *Malacosoma* caterpillars (Howlett, 1910).

Temperature preferendum values obtained in laboratory experiments for insects are generally related to the temperatures of their environments. In nature, *Fannia canicularis* emerges earlier in the year than *Musca domestica*, and in laboratory the former is active between 9° C and 35° C, while the latter is active between 14° C and 43° C. The maximum activity occurs at 21° C and 40° C, respectively (Nicholson, 1934). The preferred temperature for *Haematopinus suis* is 28.6° C (Weber, 1929).

The preferred temperature of an insect may vary during its life history. Thus in the housefly, migration from the feeding place (=dung) to pupation site (=ground) is due to behavioural changes in the central nervous system which modifies the temperature preferendum as the larvae grows. The optimum temperature during active feeding is 30° C to 34° C and drops to 17° C when ready for pupation (Thomson et al., 1937). Diurnal activity seems to be controlled by air temperature in slugs, where Dainton (1954) recorded activity between 4° C and 20° C and sensitivity to minute temperature changes such as 0.1° C in an hour. *Paramaecium*, among protozoans, also exhibits selection of preferred temperature (Mendelssohn, 1815; Loeb, 1918).

ORIENTATION IN PARASITIC ARTHROPODS

Temperature is a token stimulus for ectoparasitic arthropods which serves to lead them to their hosts by the warmth of their body. Temperature helps in securing bloodmeal for them, which they are really looking for, and not just heat. If already fed, the same insects may not exhibit any response to temperature stimulus. This response under favorable circumstances is directly proportional to the positive differential temperature of the surface between host body and environment.

Howlett (1910) showed that females of *Culex fatigans* and *Stegomyia scutellaris* may be attracted to a tube of hot water but not at all to isolated blood or human

sweat, and the males show no such reactions at all. Females of *Anopheles punctipennis*, and to a lesser extent males, also are similarly attracted to an empty heated glass plate and the former may even attack the surface with their proboscis (Marchand, 1918). This response is absent among the hibernating females of *Culex* and the wingless hoglice, *Haematopinus suis*, which obviously cannot move around to find the host by warmth and lives permanently on its host (Marchand, 1920). Temperature sensitive areas occur on the antennae of the bedbug, *Cimex lectularius* (Rivnay, 1932; Sioli, 1937). Radiant heat initiates a reaction of "hesitation in walking" and host-finding reaction is by trial and error and could be termed as a klinotactic orientation.

Wigglesworth and Gillett (1934) have studied in detail the orientation to radiant heat of the South American blood-sucking bug, *Rhodnius prolixus*. Blinded insects went straight to a test tube of warm water from a distance of 3 to 5 cm; thus vision is not involved and heat of the tube could be the only possible stimulus. The reactions disappeared on extirpation of both antennae, but not one. The bug responds to the gradient of air temperature around the source of stimulus. The receptors on the antennae perceive the gradient up an antenna when it is held along the gradient, and by moving their antennae and comparing the heat intensity which is successive in time, the insects move towards the direction of heat source. Such a movement is klinotaxis (Fraenkel et al., 1940) and not tropotaxis, since the result of unilateral removal of receptor is not circus movement, but there is a slight tendency to turn towards the intact side, which may suggest the involvement of a tropotactic element. That this is not the case may be explained by the fact that the centers of the two heat sources were 5.5 cm apart and the bugs were left 3 to 4 cm away from each source. This distance is very small and corresponds to that part of the gradient where it is hard to differentiate between klinotactic and tropotactic orientation. Theoretically, a slight deviation in a small insect on any side would yield different results. The "reflex pursuit of the antennae into the region of optimal stimulation" thus corresponds to klinotaxis and not to tropo- or telo-taxes.

Homp (1938), working with the louse, *Pediculus vestimenti*, found that its temperature preferendum was between 25 and 33° C, with a peak at about 29° C, when placed in a concentric temperature gradient by means of an "artificial hot finger." The avoiding reactions have been termed "klino-taxis" by Fraenkel and Gunn (1940), because the path assumed by the lice was wavy, but directed towards the source of stimulation and not just random in direction. Perhaps the term, "thermo-meno-taxis" used by Homp, which is comparable to light compass reaction, is not accurate since the orientation is not necessarily at a fixed angle to the direction of temperature stimulus, and there is no reason to believe that lice do not react to radiant heat. The circular path of lice near the source of temperature simply means that they were in the zone of preferred temperature and were exhibiting random undirected locomotion, which is consistent with the term "klinokinesis." Unlike *Rhodinus*, *Pediculus* without antennae can still orientate. It crawls straight to a warm tube and follows it as the tube is displaced. With equal sources of heat, most of them move halfway between the two, while some crawl directly to one of them or in a parabola to one or the other.

Using a circular apparatus heated at the center, Totze (1933) showed that the tick, *Ixodes reduvius*, exhibited a klinokinetic reaction on approaching the preferendum. The ticks show avoiding reactions to high temperature, but do not move away from low temperature gradients (Lees, 1948). In a temperature organ, ticks turn abruptly on approaching the high temperature zone, move in a straight line and get slower as the temperature drops and collect at the cool end of the gradient. This locomotion away from the hot end of the temperature organ could be indicative of a negative telotaxis, but since the reaction is dependent upon intensity of heat and it is slow towards the cool end, it may better be considered an orthokinetic reaction. It is, however, quite possible that the increased

speed of locomotion at the higher temperature is a metabolic effect of temperature and not a behavioural effect through the central nervous system. A token stimuli of warmth and odor of sheep wool both are involved in the host-finding reaction of the sheeptick, *Ixodes reduvius*.

Temperature is a token stimulus for the medicinal leech, *Hirudo medicinalis* between 33 to 35° C, which is close to the host's temperature (34.4° C), and they suck to a hot tube, but stop at 39° C and leave at 41.5° C (Herter, 1929). Similarly *Glossiphonia complanata*, an invertebrate parasite, comes to a tube at 26° C, and the fish leech, *Hemiclepsis* at 31° C (Herter, 1928).

ORIENTATION OF LOCUSTS TO RADIANT HEAT

The gregarious hoppers of the locust, *Locusta migratoria migratorioides*, have a fairly definite daily routine of behaviour. Chapman (1955) writes, "At night they are quiescent on plants (=roosting). At dawn they become active and ascend higher up the stems. Feeding follows until, when the morning is well advanced, the hoppers descend from the plants and soon form basking groups. Depending on conditions, the basking group persists or the hoppers start to march. If marching occurs, it stops as evening approaches and basking groups are formed again. These later break up and the hoppers ascend to the night roosting positions, feeding until the temperature becomes too low." The sense organs involved in temperature perception have already been mentioned (table 1) and the following account is a critical review and analysis of the various movements in locusts in relation to solar radiation. The behaviour of locusts can be conveniently described under the following divisions: first movements, morning ascent and exposure to sun, morning descent, and evening ascent.

First movements.—The first movement is awakening with the sunrise, and two factors can operate in the field, light intensity and temperature, which are rapidly changing at this time, but humidity is also possible as a third factor. At 15° C cold stupor occurs in *Locusta* (Hussein, 1937) so that insects that often do not move until after sunrise are able to exhibit responses to light, but can not do so because of the low temperature. Chapman (1955) found that below 20° C restricted movements can occur, so photokinesis is not considered as a major factor. The major factor in awakening is positive thermokinesis, with photokinesis playing a minor role.

Morning ascent and exposure to sun.—As the temperature rises, a negative response to gravity occurs which is the main cause of the ascent (Lepiney, 1933; Kennedy, 1939; Regnier, 1931; and Chapman, 1955). There is no indication in laboratory tests that hoppers can move along a temperature gradient, and we also know that below 15° C cold stupor onsets, so the only role of temperature in morning ascent could be one of increasing the metabolic activity. Morning ascent results in exposure to radiant heat, and this is a transient period since very soon the heated hoppers begin to descend.

Morning descent.—It is a well-known phenomenon that as the sun rises high the hoppers descend from their host plants. There are two factors involved in the field during morning descent, the actual downward movement or descent of the hoppers, and another factor, of suitable ground temperature for basking which prevents hoppers from reascending after descent and is responsible for vacation of the roosting sites. There are reasons to believe that it is not just a matter of chance or due to negative phototaxis (Kennedy, 1939) or change in relative humidity (Zolotarevsky, 1933), but a thermotactic response (Fraenkel in Bodenheimer, 1929).

It has been shown in laboratory experiments that an inverted air temperature gradient plays no part in morning descent (Chapman, 1955). Husain (1932) found no descent in *Schistocerca* even at 45° C when the temperature conditions were uniform, indicating that it is very necessary for the ground temperature to exceed air temperature if the roosts are to be vacated. Similar results are

obtained by Rubtzov (1935), Strelnikov (1936), and Kennedy (1939). Air movement affects mechanically, or by causing a fall in body temperature, thus resulting in increased activity and descent.

Evening ascent.—In the evening the hoppers leave their basking groups and ascend on the surrounding vegetations. This phenomenon roughly coincides with sunset and when the ground is cooled. Ascent occurs in *Locusta migratoria migratorioides* two hours before sunset (Shumakov, 1940), not until sunset if ground temperature does not fall earlier in *L. migratoria capita* (Zolotarevsky, 1930), and about half an hour before sunset in *Schistocerca* (Regnier, 1931).

No evidence was obtained in laboratory tests for a role of positive phototaxis in the evening ascent (Chapman, 1955), although some people suggest it to be the case in field (Allan, 1933; Kennedy, 1939; Kiritchenko, 1926; Pielou, 1948; and Telenga, 1930). The ascent can not be considered as due to an inherent tendency on the part of the locust to sit head upwards in a vertical position as has been suggested by Williams (1933), since there is tremendous variation in posture of sitting. The works of Burnett (1951), Fraenkel (1929), Kennedy (1939), Pielou (1948), and Regnier (1931) all point at the importance of negative geotaxis in the evening ascent.

Under laboratory conditions, Chapman (1955) found that hoppers did not start to ascend until the ground temperature dropped, and until the activity of the hoppers was such that they ceased to bask, but there was a tendency to stay up after once ascending on roosting sites. The roosting position was disturbed by increased air temperature since the hoppers became highly active and could not maintain their position. Recent feeding inhibited this activity. It is possible for the hoppers to follow the sun up as a temperature response, but body temperature is not found to be a factor in evening ascent.

It could be concluded from these observations that the behaviour of locusts is mostly random, undirected, and kinetic, while upward climbing and roosting following the evening ascent may be directed and taxic. Of all the internal and external factors modifying their behaviour, radiant heat appears to be by far the most important, especially in orientation to solar radiation.

ACKNOWLEDGEMENT

The writer is thankful to Professor G. S. Fraenkel for his suggestions and for lending some valuable papers on this subject.

LITERATURE CITED

Alexander, A. J., and **D. W. Ewer.** 1958. Temperature adaptive behaviour in the scorpion, *Opisthothalmus latimanus*. J. Exptl. Biol. **35**: 349–359.

Allan, W. 1933. The movement and breeding of locust swarm (July 1931–Sept. 1932). Ann. Bull. Dept. Agr. N. Rhod. **2**: 25–34.

Bazett, H. C., B. McGlone, and **R. J. Brocklehurst.** 1930. Stimulation of cutaneous thermoreceptors in man. J. Physiol. **69**: 88–112.

Bazett, H. C. 1941. In Temperature, Its Measurement and Control in Science and Industry. Reinhold, New York. pp. 489–501.

Bodenheimer, F. S., and **D. Schenkin.** 1928. Die temperatur abhängigkeiten einiger Insekten. Zeit. f. vergl. Physiol. **8**: 1–15.

———. 1930. Studien zur Epidemiologie, Ökologie und Physiologie der afrikanischen wanderheuschrecke (*Schistocerca gregaria*, Forsk.). Zeit. angew. Entomol. **15**: 1–123.

Burnett, G. F. 1951. Field observations on the behaviour of the red locust (*Nomadacris septemfasciata* Serville) in the solitary phase. Anti-Locust Bull., London. no. 8, 36 pp.

Buxton, P. A. 1924. Heat, moisture and animal life in deserts. Proc. Roy. Soc. Lond. (B) **96**: 123–131.

Cappe de Baillon, P. 1932. La sensibilite thermique des Phasmidae. Compt. Rend. Acad. Sci. Paris **195** (3): 557–559.

Chapman, R. F. 1955. Some temperature responses of nymphs of *Locusta migratoria migratorioides* (R.&F.), wiht special reference to aggregation. J. Exptl. Biol. **32**: 126–139.

———. 1955. A laboratory study of roosting behaviour in hoppers of the African Migratory Locust (*Locusta migratoria migratorioides* R. & F.). Anti-Locust Bull., London. no. 19, 40 pp.

Cowles, R. B. 1947. Comments by readers. Science 105: 282.
Dainton, B. H. 1954. The activity of slugs. J. Exptl. Biol. 31: 165–197.
Dijkgraaf, S. 1943. Temperature sense in fish. Zeit. f. vergl. Physiol. 30: 252.
Dodt, E., and **Y. Zotterman.** 1952. The discharge of specific cold fibres at high temperatures. Acta Physiol. Scand. 26: 358–365.
Dotterweich, H. 1928. Beitrage zur Nervenphysiologie der Insekten. Zool. Jahrb. Abt. allg. f. Zool. u. Physiol. 44: 399–450.
Fraenkel, G. 1929. Untersuchungen uber Lebensgewohnheiten, Sinnesphysiologie und Sozialpsychologie der wandernden Larven der afrikanischen Wanderheuschrecke *Schistocerca gregaria* (Forsk.). Biol. Zentralbl. 49: 657–680.
———. 1930. Die Orientierung von *Schistocerca gregaria* zu strahlender Wärme. Zeit. f. vergl. Physiol. 13: 300–313.
——— and **L. D. Gunn.** 1940. The Orientation of Animals. Oxford. 318 pp.
Franz, H. 1930. Untersuchungen uber den Wärmehaushalt der Poikilothermen. Biol. Zentralbl. 50: 158–182.
Gebhardt, H. 1951. Lokalisatorischer Nachweis von Thermorezeptoren bei *Dorcus parallelepipedus* L. und *Pyrrhocoris apterus* L. Experientia, Basle, 7: 302–303.
———. 1953. Die Lage de wichstigsten Thermorezeptoren bei einigen Insekten. Zool. Jb. Jena (Allg. Zool.) 63: 558–592.
Geist, R. M. 1928. The heat sensitive areas of certain grasshoppers. Ann. Entomol. Soc. Am. 21: 614–618.
Gunn, D. L. 1934. Temperature and humidity relations of the cockroach. II. Temperature preference. Zeit. f. vergl. Physiol. 20: 617–625.
——— and **C. A. Cosway.** 1938. Humidity preference of *Blatta orientalis*. J. Exptl. Biol. 13: 450–459.
———. 1942. Body temperature in poikilothermal animals. Biol. Rev. 17: 293–314.
Henson, W. R., and **R. F. Shepard.** 1952. The effects of radiation on the habitat temperatures of the lodgepole needle miner, *Recurvaria milleri* Busck. (Gelechidae: Lepidoptera). Canad. J. Zool. 30: 144–153.
Herter, K. 1923. Temperatursinn der Hausgrille (*Acheta domestica*) und der roten Waldameise (*Formica rufa*). Biol. Zentralbl. 43: 282–285.
———. 1924. Temperatursinn einiger Insekten. Zeit. f. vergl. Physiol. I: 221–288.
———. 1926. Thermotaxis und Hydrotaxis bei Tieren. Bethes Handb. norm. path. Physiol. II: 173–180.
———. 1928. Reizphysiologie und Wirtsfindung des Fischegels, *Hemiclepsis marginata*. Zeit. f. vergl. Physiol. 8: 391–444.
———. 1929. Reizphysiologisches Verhalten und Parasitismus des Entenegels, *Protoclepsis tesselata*. Zeit. f. vergl. Physiol. 10: 272–308.
———. 1932. Nachträge zu Herter, 1926. Bethes Handb. norm. path. Physiol. 18: 280–282.
———. 1939. Über den Temperatursinn der Insekten. In 7 int. congr. Entomol. 2: 740–759.
Hesse, R. 1924. Tiergeographie auf Ökologischer Grundlage. Jena, Fischer. pp. 164–165.
Himmer, A. 1932. Dei temperaturverhaltnisse beiden Sozialen Hymenopteren. Biol. Rev. 7: 224–253.
Hodgson, E. S., and **K. D. Roeder.** 1956. Electrophysiological studies of arthropod chemoreception. I. General properties of labellar chemoreceptors in diptera. J. Cell. Comp. Physiol. 48: 51–76.
Homp, R. 1938. Warmeorientierung von *Pediculus vestimenti*. Zeit. f. vergl. Physiol. 26: 1–34.
Howlett, F. M. 1910. The influence of temperature upon the biting of mosquitoes. Parasitology 3: 479–484.
Huard, G., and **R. P. Corbe.** 1951. Recherches photometriques sur *Parnassius apollo* L. (Lepidopteres). Bull. Soc. Zool. France 76: 18–21.
Husain, M. A. 1932. Report of the locust research entomologist at Lyallpur, West Pakistan. ii+105 pp. (unpublished).
Hussein, M. 1937. The effect of temperature on locust activity. Bull. Minist. Agr. Egypt, Cairo. no. 184, 55 pp.
Kennedy, J. S. 1939. The behaviour of the desert locust (*Schistocerca gregaria* Forsk.) (Orthoptera) in an outbreak centre. Trans. Roy. Entomol. Soc. Lond. 89: 385–542.
Kerkut, G. A., and **B. J. R. Taylor.** 1957. A temperature receptor in the tarsus of the cockroach, *Periplaneta americana*. J. Exptl. Biol. 34: 486–493.
Kiritchenko, A. 1926. Materials for the ecology and bionomics of *Calliptamus italicus*, L., in the steppe zone of Ukraine. Odes'ka Reg. Agr. Exp. Sta., Entomol. Dept. I: 47 pp. (In Russian).
Krogh, A., and **E. Zenthen.** 1941. The mechanism of flight preparation in some insects. J. Exptl. Biol. 18: 1–10.
Krüger, P. 1929. Über die Bedeutung der ultraroten Strahlen fur den Warmehaushalt der Poikilothermen. Biol. Zentralbl. 49: 65–82.
Lees, A. D. 1948. The sensory physiology of the sheep tick, *Ixodes ricinus*. J. Exptl. Biol. 25: 145–207.

Lengerken, H. von. 1924–27. Coleoptera. Käfer. P. Schulze, Biologie Tiere Deutschlands, Berlin (Lfg. 10, 12, 16, 24), Teil 40: 1–346.
Lepiney, J. de. 1933. Revision sommaire du comportement de *Schistocerca gregaria* Forsk., ph. *gregaria*, dans les lieux d'habitat temporaire. In 5 int. congr. Ent., Paris (1932): 573–584.
Loeb, J. 1918. Forced Movements, Tropisms and Animal Conduct. J. B. Lippincott Co., Philadelphia. pp. 155.
Marchand, W. 1918. First account of a thermotropism in *Anopheles punctipennis*, with bionomic observations. Psyche 25: 130–135.
———. 1920. Thermotropism in insects. Entomol. News. 31: 159–165.
Mendelssohn, M. 1895. Über den Thermotropismuseinzelliger Organismen. Arch. ges. Physiol. 60: 1–27.
Morgan, A. H. 1922. The temperature senses in the frog's skin. J. Exptl. Zool. 35: 83–114.
Nicholson, A. J. 1934. Influence of temperature on the activity of sheep blowflies. Bull. Entomol. Res. 25: 85–99.
Noble, G. K., and **A. Schmidt.** 1937. The structure and function of the fascial and labial pits of snakes. Proc. Am. Phil. Soc. 77: 263–288.
Oosthuizen, M. J. 1939. Muscle temperature before and during flight in insects. J. Entomol. Soc. S. Africa 2: 63–73.
Pielou, D. P. 1948. Observations on the behaviour of gregarious hoppers of the red locust, *Nomadacris septemfasciata* Serville. Proc. Roy. Entomol. Soc. Lond. (A) 23: 19–27.
Pirsch, G. B. 1923. Studies on the temperature of individual insects, with special reference to the honeybee. J. Agr. Res. 24: 275–288.
Prinz, I. Y. 1928. On the pests of the vine. Entomol. Cab. Agr., Co-oper. Soc. Concordia, Tiflis, 2: 127 pp. (In Russian).
Prosser, C. L. 1952. Comp. Animal Physiol. Saunders Co., Philadelphia. p. 374.
Regnier, P. P. 1931. Les acridiens ravageurs du Maroc. Rabat, Dir. gen. Agr. Comm. et Colon., Def. cultures, 41 pp. (2nd edition).
Rivnay, E. 1932. The tropisms of the bedbug, *Cimex lectularius*. Parasitology 24: 121–136.
Rubin, M. A. 1935. Thermal reception in fishes. J. Gen. Physiol. 18: 643–647.
Rubtzov, I. A. 1935. Regularities in the development and behaviour of Siberian Acrididae in connection with climatic factors. Bull. Acad. Sci. U.R.S.S., Leningrad 1935: 789–824. (In Russian with German summary).
Sand, A. 1938. The function of the ampullae of Lorenzini, with some observations on the effect of temperature on sensory rhythms. Proc. Soc. Lond. (B) 125: 524–553.
Schroder, C. 1903. Kritik der von Herrn Dr. E. Fischer (Zürich) aus seinen "Lepidopterologischen Experimentalforschungen" gezogenen Schlüsse auf Grund einer enuen Erklärung des Wesens derselbent. Allg. Zeit. Entomol. 8: 437–447.
Shumakov, E. M. 1940. The cause of gregariousness in Acrididae. Proc. Lenin Acad. Agr. Sci., Leningrad. 21: 10–15 (In Russian).
Sioli, H. 1937. Thermataxis und Perzeption von Wärmestrahlen bei der Bettwanze, *Cimex lectularius*. Zool. Jahrb. Abt. allg. f. Zool. u. Physiol. 58: 284–296.
Slifer, E. H. 1951. Some unusual structures in *Locusta migratoria migratorioides* and their probable functions as thermoreceptors. Proc. Roy. Soc. (B) 138: 414–437.
———. 1953. The pattern of specialized heat sensitive areas on the surface of the body of Acrididae (Orthoptera). Trans. Am. Entomol. Soc. 79: 37–97.
Strebel, O. 1932. Beiträge zur Biologie, Ökologie und Physiologie einheimischer Collembolen. Zeit. f. Morphol. u. Okol. Trere 25: 31–153.
Strel'nikov, I. D. 1936. Effect of solar radiation and microclimate upon the body temperature and behaviour of the larvae of *Locusta migratoria* L. Trav. Inst. Zool. Acad. Sci. U.R.S.S., Leningrad 2(1935): 637–733. (In Russian with English summary).
Szilady, Z. 1921. Thermoskopische Farben im Tierreich. Festschriftzum II. Ferienhochschulkurs, Nagy Szeben. pp. 65–84.
Telenga, N. A. 1930. Biological observations on *Schistocerca gregaria*, Forsk. in Kohresm in 1929. Izre, Khoresm sel-Khoz. Opuit., Moscow 6: 27 pp. (In Russian).
Thomson, E., and **M. Thomsen.** 1937. Über das Thermopräferendum der Larven einiger Fliegenarten. Zeit. f. vergl. Physiol. 24: 343–380.
Totze, R. 1933. Sinnesphysiologie der Zecken. Zeit. f. vergl. Physiol. 19: 110–161.
Weber, H. 1929. Biologische Untersuchungen an der Schweinlaus (*Haematopinus suis* L.) unter besonderer Berücksichtigung der Sinnesphysiologie. Zeit. f. vergl. Physiol. 9: 564–612.
Wigglesworth, V. B., and **J. D. Gillett.** 1934. The function of the antennae in *Rhodnius prolixus* (Hemiptera) and the mechanism of orientation to the host. J. Exptl. Biol. II: 120–139.
Williams, C. B. 1933. Observations on the desert locust in East Africa from July 1928 to April 1939. Ann. Appl. Biol. 20: 463–497.
Zolotarevsky, B. N. 1930. Le Criquet Migrateur (*Locusta migratoria* Sauss.) a Madagascar. Ann. Epiphyt., Paris 15 (1929): 185–236.
———. 1933. Contribution a l'etude biologique du Criquet Migrateur (*Locusta migratoria capito*, Sauss.) dans des foyer permanents. Ann. Epiphyt., Paris 19: 47–142.

ADDITIONAL STUDIES OF DISPERSION PATTERNS OF AMERICAN COCKROACHES FROM SEWER MANHOLES IN PHOENIX, ARIZONA

WILLIAM B. JACKSON[1] AND PAUL P. MAIER

Communicable Disease Center, Public Health Service, U.S. Department of Health, Education, and Welfare, Phoenix, Arizona

Cockroaches in abundance are often associated with human activities and, thus, are convenient animals for ecological experiments. As a matter of general concern, cockroaches often live in association with filth and are known to carry a large number of microorganisms, some of which are pathogenic to man (Roth and Willis, 1957). That cockroaches might serve as elevator mechanisms, bring enteric disease organisms from underground sewer systems up to areas of human contact, prompted a series of experiments to determine the various factors affecting movement patterns in American cockroach (*Periplaneta americana* [L]) populations.

An initial study in Phoenix, Arizona, determined that during the summer American cockroaches had limited movements from sewer manholes under undisturbed conditions but extensive emigration when the manhole population balance was disrupted by the super-imposition of a large number of extraneous roaches (Jackson and Maier, 1955). Movements into yards, an adjacent apartment, and 350 ft downstream in the sewers were recorded.

The following dispersal tests were a continuation of these studies to determine movement patterns in other seasons. The possible inhibitory effects of cooler weather on roach movements were investigated during January 1954; and, since some miscellaneous observations had indicated increased numbers of cockroaches above ground during the late spring, dispersion patterns were investigated also during June 1954.

METHODS AND PROCEDURES

A paired manhole experimental design, similar to that of the previous experiment (Jackson and Maier, 1955), was used. The cockroach population in one manhole was removed, marked, and immediately returned to its source. At the same time, in a comparable manhole on a different sewer lateral, a thousand or more marked cockroaches, collected from other sections of the city, were superimposed on the resident cockroach population. The dispersion patterns of these two populations were compared by recoveries of marked individuals in traps set in yards, apartments, and manholes up and down stream from the release site. This approach was designed to determine behavior patterns occurring under the usual, undisturbed conditions as well as those resulting from concentrations of large numbers of roaches, such as might occur during sewer stoppages or flooding.

In addition, a release with superimposition of marked roaches was carried out in the manhole in a Latin-American housing project from which extensive dispersion had been demonstrated during the previous summer's tests. This was done to compare the dispersion patterns in two somewhat different environments. Population samples prior to each new release indicated that no marked individuals remained from the previous experiment.

American cockroaches, the only cockroach species inhabiting sewer manholes in Phoenix, were collected with traps consisting of one-quart wide-mouthed mason jars having an inward-directed, plastic screen cone held in place by a standard

[1]Present address: Department of Biology, Bowling Green State University, Bowling Green, Ohio.

cover ring. Ripe bananas served as bait. A vacuum cleaner with a padded receiving attachment was used when all the cockroaches were to be removed from a manhole. The use of carbon dioxide gas facilitated handling the cockroaches. The same traps, slipped into half-gallon ice cream cartons to reduce light intensity, were placed in yards in tall grass, under bushes, near garbage cans, or adjacent to building foundations. Traps used in apartments were usually placed on the floor in kitchens or occasionally in bathrooms and were without cartons.

The cockroaches were marked in the laboratory with radioactive phosphorus (P^{32}) by spraying groups up to 1000, held in a garbage can, with about 75 ml of a 5 percent aqueous casein solution containing 10 μc of P^{32}/ml. This resulted in an average individual tag intensity of several thousand counts per minute. A beta-gama radioactivity monitor (Model 1615, Radiation Sentinel, Nuclear-Chicago) was used to measure the intensity of the beta radiation. The cockroaches were placed about 0.5 cm from the window of the Geiger tube.

In addition to the American cockroach, the German cockroach (*Blatella germanica* [L]) and the brown-banded cockroach (*Supella supellectilium* Serv.) were caught both indoors and outdoors, and the field roach (*Blatella vaga* Hebard) was caught only outdoors. These additional species are not considered in this discussion.

Winter dispersion. A well sanitated, Anglo-American housing project was used for the winter experiments. The manhole in which the resident population was marked exposed drainage from several rows of apartments having a total of 20 units. Upstream manholes were 273 and 421 ft distant; downstream manholes were 273, 431, and 629 ft away, the latter being the juncture with a trunk sewer line.

The cockroach population of 300 was removed, marked, and returned to the manhole on January 19. Trapping was done in surrounding yards, homes, and manholes for the succeeding 9 days.

An extraneous group of 1500 cockroaches was superimposed on a manhole population of 125 roaches in another part of the same project on January 14. This manhole exposed drainage from a quadrangle of 36 apartments. A single manhole existed 180 ft upstream, and manholes downstream were at distances of 173, 333, 490, 670, and 833 ft. Intensive trapping continued for 11 days.

The comparison release test in the Latin-American housing project occurred on January 29 when 1300 cockroaches were superimposed on a native population of 275. This manhole exposed drainage from a quadrangle of 24 apartments. A single upstream manhole was 165 ft distant, and downstream manholes were 185, 350, 535, and 700 ft away. Intensive trapping was done for 10 days.

The resident roach populations in the latter two releases were not marked. To have used radioactive phosphorus tags on those would have made them indistinguishable from the superimposed individuals, and other techniques were not employed. Movements of such resident roaches cannot be determined from these experiments.

Spring dispersion. The late spring experiments were carried out in a fairly well sanitated, Negro housing project. The manhole in which the resident population was marked exposed drainage from an apartment quadrangle of 24 units. A single manhole was 165 ft upstream, and manholes were downstream at distances of 160, 325, 410, and 495 ft, the next to the last being a trunk sewer line juncture. In this test the cockroach population of 700 was tagged on June 3, and intensive trapping was carried on for 2 weeks.

An extraneous group of 2000 marked cockroaches was superimposed on an unmarked resident manhole population of 400 on June 4. This manhole exposed drainage from a series of apartment rows, a total of 22 units. Two upstream manholes were at distances of 160 and 525 ft; the first two manholes downstream,

145 and 620 ft distant, were on a trunk line. Intensive trapping was carried on for two weeks.

A comparison release in the Latin-American project was made on June 8, when 1300 tagged cockroaches were superimposed on the unmarked resident population of 600. Intensive trapping was continued for two weeks.

RESULTS

Winter dispersion.—No radioactive cockroaches were recovered from the winter releases outside of the manhole with the marked resident population, and only one individual was recovered from the release with superimposed roaches (table 1). This individual, caught without the use of a trap 10 ft from the manhole several minutes after garbage cans nearby had been emptied, presumably had emerged through a hole in the manhole cover and taken refuge in or among the cans.

TABLE 1

Summary of trapping results in two American cockroach dispersion experiments

January experiment	No. roaches marked	Apt. traps	Yard traps	Manhole traps
Resident population	300			
Number of traps		24	29	5
Number of trap nights*		206	257	39
Total number of roaches caught		2	0	117
No. marked roaches recaptured		0	0	0
Superimposed population	1500			
Number of traps		31	40	5
Number of trap nights*		356	415	65
Total number of roaches caught		1	0	443
No. marked roaches recaptured		0	1**	0
Reference superimposed population	1300			
Number of traps		20	31	4
Number of trap nights*		181	305	40
Total number of roaches caught		631	5	337
No. marked roaches recaptured		0	2	0
June experiment				
Resident population	700			
Number of traps		27	33	5
Number of trap nights*		366	411	60
Total number roaches caught		46	4	1425
No. marked roaches recaptured		0	0	8
Superimposed population	2000			
Number of traps		19	24	4
Number of trap nights*		241	316	53
Total number roaches caught		38	40	495
No. marked roaches recaptured		7	29	2
Reference superimposed population	1300			
Numer of traps		—	29	5
Number of trap nights*		—	374	70
Total number of roaches caught		—	48	2901
No. marked roaches recaptured		—	17	56

*A trap night is one trap operating for one night.
**Recovered in alley without use of trap.

Only two radioactive individuals were recovered in the comparison release test in the Latin-American housing project. Both were caught in yard traps, one 10 ft and the other 60 ft from the release site manhole. No marked roaches were recovered from adjacent manholes. Similarly, no marked cockroaches were found in manholes adjacent to release sites when these manholes were cleared of roaches with the vacuum cleaner at the termination of the trapping period. A

repetition of this procedure 2 to 3 weeks later was likewise negative. Population samples taken from the release sites at the close of the experiment showed 69 of the 70 cockroaches from the resident manhole and 48 of the 58 individuals from the manhole with superimposed roaches to be radioactive.

Spring dispersion.—During the spring dispersion tests eight marked cockroaches were recovered from the manhole with only the resident population tagged. One was found in the manhole 160 ft downstream and seven were recovered from the manhole 325 ft downstream. After two weeks of trapping, vacuum cleaner collections from adjacent manholes produced no additional radioactive individuals.

Thirty-eight marked cockroaches were recovered outside the superimposition manhole (fig. 1). Of the seven caught in apartment traps, single catches occurred in two traps, each 90 ft from the manhole, and the remaining five came from an apartment 28 ft away.

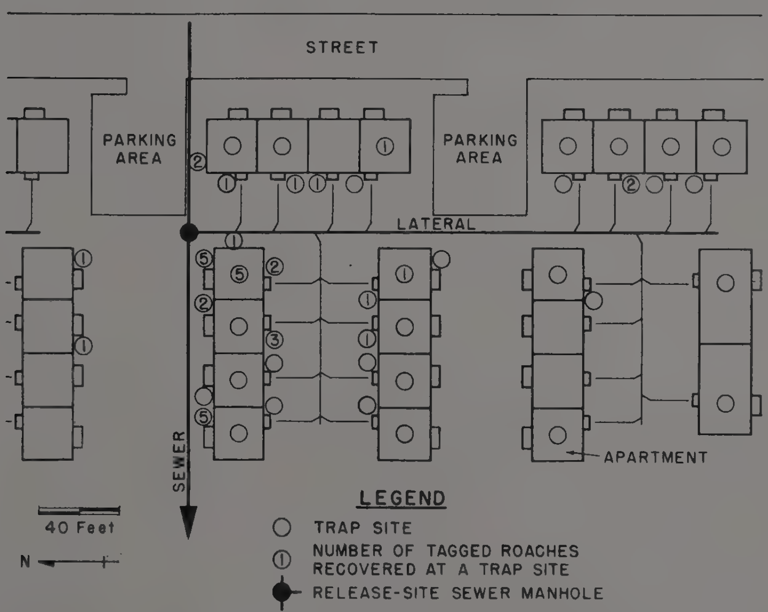


FIGURE 1. Apartment area in Phoenix, Arizona, showing the release and recovery sites of tagged American cockroaches for the June experiment where extraneous roaches were superimposed on an existing population.

Fifteen yard traps caught 29 tagged individuals, and about half were caught within 50 ft of the release site. Following is an enumeration of trap distances in feet with the number of marked cockroaches caught shown in parentheses: 15 (5), 23 (1), 28 (2), 38 (2), 38 (1), 50 (2), 50 (1), 55 (1), 65 (5), 70 (3), 70 (1), 73 (1), 90 (1), 95 (1), and 200 (2). Two radioactive cockroaches were trapped in the manhole 475 ft downstream and a single tagged individual was recovered 145 ft downstream (with the vacuum cleaner) after the trapping period.

From the reference release with superimposed roaches in the Latin-American project, 73 tagged cockroaches were recovered by trapping. No apartment traps were placed during this period. Seventeen roaches entered nine yard traps.

Trap distances in feet are listed with the number of marked roaches shown in parentheses: 30 (4), 33 (1), 38 (1), 40 (1), 48 (2), 50 (1), 60 (3), 75 (2), and 95 (2).

Manhole traps caught 56 released individuals. The upstream manhole (165 ft) had 13, and the first downstream manhole (185 ft) had 43. Removing roaches from the manholes by vacuum cleaner after the trapping period produced an additional 3 from the former and 27 from the latter. No radioactive cockroaches were found in the manholes further downstream.

DISCUSSION

Dispersal has been described as "the innate tendency . . . which seems to be present to a greater or smaller degree in all animals [and] may [be] accentuated by crowding, hunger, warmth, wind, and so on" (Andrewartha and Birch, 1954). Experiments with various natural insect populations have shown largely random movement from a point of concentration (the release site of several thousand or more marked individuals) for fruit flies (Dobzhansky and Wright, 1943), several species of domestic flies (Bishopp and Laake, 1921; Lindquist et al., 1951; Schoof et al., 1952), and codling moths (Steiner, 1940). These movements were often considerably influenced by topography, winds and other climatic factors, and the nature and locations of attractants and traps.

To ascribe innateness to a behavior pattern may mask the full explanation, since the environment, both physical and biotic, plays such an overwhelming role in the development and function of the innate. The present experiments attempt to relate certain patterns of movement of cockroaches with associated environmental conditions. Under stress conditions, dispersal movements usually occurred; but under undisturbed conditions virtually no movement could be detected with the techniques used.

The movement pattern of cockroaches resulting from the creation of a population greater than the carrying capacity of the environment has been shown under summer conditions in Phoenix, Arizona (Jackson and Maier, 1954). In a superimposition type of experiment, 5.9 percent of the 1200 cockroaches released were recaptured at distances up to 350 ft from the release-site manhole. In contrast, only 0.8 percent of the 500 individuals marked in an undisturbed population were recaptured at distances up to 170 ft.

This pattern of marked movement away from a site of positive population pressure could not be replicated in a cooler, winter period. Measurable dispersion of the marked cockroaches from manholes was either very small or nonexistent, regardless of whether or not extraneous individuals were superimposed on the resident population.

Some movement into appurtenant laterals evidently took place during January, since manhole populations did not remain at high levels after extraneous roaches were introduced, but was of too short a distance to be detected by the trapping procedure used. No dispersion of roaches through the keyhole in the manhole cover occurred during the 80 min immediately following the release of superimposed roaches at the Latin-American Housing Project, and there were no clusters of cockroaches around the keyhole on the underside of the lid during this time.

Roaches in the manhole were observed to move much more slowly than during the summer; and the numbers of cockroaches entering traps, both in manholes and in apartments, were considerably reduced despite large populations observed in the manholes and reported by householders. Temperature probably played the major role in this changed activity pattern. The mean temperature reported by the U. S. Weather Bureau in Phoenix for January was 52° F with an average maximum of 66° F and minimum of 38° F. Manhole temperatures, recorded by hygrothermographs suspended in the manhole near the floor, averaged about 66° F, with maximum and minimum temperatures of 72° F and 55° F, respectively. In contrast, summer maximums in Phoenix average above 100° F with a mean of

about 90° F, and mean manhole temperatures average above 95° F, with individual manholes having a daily termal range of about 5 Fahrenheit degrees.

The dispersion pattern in the late spring (June) was similar to that observed during the previous summer. Where only the resident population was tagged, observed movement was limited to downstream manholes. However, when the manhole population balance was drastically disrupted by the superimposition of roaches, extensive emigration into adjacent manholes, yards, and apartments occurred.

The fact that large-scale movement of roaches into adjacent manholes from the one with superimposed individuals did not occur in the June test, as it did in the comparison tests in the Latin-American project, is not adequately explained. These adjacent manholes had satisfactory microclimates as judged by the results of other studies made in Phoenix; but still they had few or no cockroaches, even prior to the experiment.

Twenty-four cockroaches were counted between 2000 and 2100 hours emerging from this superimposition site manhole through holes in the cover the night after the release. Individual roaches were observed to run a short distance over the cover, then go back into a hole and, in some cases, emerge again later. Others ran directly away from the manhole into the grass. Roaches that were followed moved slowly through the grass, and some eventually came to rest on the walls of nearby apartments. Clusters of cockroaches were observed around the inner edge of each cover hole.

Similar observations at the Latin-American project manhole the night after the release revealed seven cockroaches leaving in 40 min between 1950 and 2030 hours. Subsequent observations indicated that this pattern continued in both sites during the course of the experiments. These dispersal movements were not observed to occur from manholes where only resident roaches were studied.

The entry portal of the cockroaches into apartments was of particular interest in these studies because some marked roaches were recovered from apartments. Cockroaches were observed to be strong swimmers whenever they fell into the sewage stream; and they will readily traverse plumbing water traps, at least in the laboratory, as has been demonstrated in our laboratory and elsewhere (Anon., 1953). Thus most plumbing connections offer the cockroaches a readily available portal of entry into homes from sewer systems.

In the present experiments, cracks under the doors seemed to be an added important means of entry. Housewives complained of many cockroaches and other insects crawling under the doors at night. One resident killed a cockroach just after it had entered a home from under a door, and subsequent examination showed it to be a marked individual released in the sewer manhole. However, the determination of the mode of entry into homes of recaptured roaches was not attempted in these studies.

Adult females predominated in the recoveries of tagged cockroaches, regardless of place or season of year. A summary of all the recovery records shows that of the 216 radioactive individuals recaptured, 150 (69%) were adult females, 8 (4%) were adult males, and 58 (27%) were nymphs; and of the nymphs 73 percent were caught in manholes. Of the 44 cockroaches seen as they emerged from holes in manhole covers, no nymph was recorded, and 34 were listed as adults. Dim illumination prevented accurate classification of the remainder.

At least 40 percent of the individuals marked in each experiment were nymphs, and about 75 percent of the adults were females. On this basis, greater proportions of nymphs and males would have been expected among the recaptures than were actually found. That differential trapping success is not the explanation is indicated by generally similar proportions of nymphs to adults and sexes in both trap and vacuum cleaner collections. This would then seem to indicate that adults, and particularly females, are primarily involved in population pressure

adjustments. The possibility of differential mortality cannot be excluded, but no field data are available to evaluate this hypothesis. In the laboratory, Gould and Deay (1940) found that males tended to have a shorter life span than females.

Observations on sewer manhole cockroach populations in other studies in Phoenix have indicated that minimum population levels occur in late winter and that a population increase occurs in late spring. This increase may be associated with a movement of individuals from appurtenant laterals into manholes with the advent of warmer weather. An increase in the proportion of adults also occurs.

These factors appear to establish a suitable basis for the increased outdoor occurrences of cockroaches in the late spring and summer. With both the increase in total numbers of individuals and in the proportion of adults, the carrying capacity of the environment may be exceeded, and equilibrium is reestablished by means of emigration. Evening observations indicated that emigration through holes in manhole covers was occurring from some of the manholes not involved in the experiments but with histories of large populations in the Latin-American housing project.

These studies have indicated that the sporadic movement of American cockroaches from sewer manholes may be somewhat increased during the late spring by population readjustments and that major disruptions of population balances, such as from sewer flooding may well result in extensive emigration. While an occasional cockroach moving out from a contaminated area is of little importance epidemiologically, extensive emigrations could convert cockroaches into important elevators of enteric pathogens.

SUMMARY

Additional studies of the movements of American cockroaches (*Periplaneta americana* [L.]) from sewer manholes in Phoenix, Arizona, were made using a radiophosphorus marking technique. Little or no movement was recorded during a winter experiment, even when 1500 extraneous cockroaches were superimposed on a resident manhole population of 125. In late spring experiments, limited movement was recorded from an undisturbed manhole population, but extensive emigration resulted from the superimposition of 2000 extraneous cockroaches on a manhole population of 400. Recoveries of tagged individuals were made in nearby yards, apartments, and manholes. About 50 percent of the yard recoveries were made within 50 ft of the release site manhole, but some recaptures were made up to 200 ft away and from a manhole 475 ft downstream. These results indicate that a sudden population increase may result in widespread cockroach emigration and that some emigration may normally occur in the spring and summer from populations readjusting to the carrying capacity of their environment.

REFERENCES

Andrewartha, H. G. and **L. C. Birch.** 1954. The Distribution and Abundance of Animals. University of Chicago Press. Chicago, 782 pp.

Anonymous. 1953. The Tyler Project. Texas Health Bull. 6: 12–15.

Bishopp, F. C. and **E. W. Laake.** 1921. Dispersion of flies by flight. J. Agric. Res. 21: 729-766.

Dodzhansky, T. and **S. Wright.** 1943. Genetics of natural populations. X. Dispersion rates in *Drosophila pseudoobscura*. Genetics 28: 304–340.

Gould, G. E. and **H. O. Deay.** 1940. The biology of six species of cockroaches which inhabit buildings. Purdue Univ., Agric. Expt. Sta. Bull. 451: 1–31.

Jackson, W. B. and **P. P. Maier.** 1955. Dispersion of marked American cockroaches from sewer manholes in Phoenix, Arizona. Am. J. Trop. Med. Hyg. 4: 141–146.

Lindquist, A. W., W. W. Yates, and **R. A. Hoffman.** 1951. Studies of the flight habits of three species of flies tagged with radioactive phosphorus. J. Econ. Entomol. 44: 397–400.

Roth, L. M. and **E. R. Willis.** 1957. The medical and veterinary importance of cockroaches. Smithsonian Misc. Coll. 134: 1–47.

Schoof, H. F., R. E. Siverly, and **J. A. Jensen.** 1952. House fly dispersion studies in metropolitan areas. J. Econ. Enomol. 45: 675–683.

Steiner, L. F. 1940. Codling moth flight habits and their influence on results of experiments. J. Econ. Entmol. 33: 436–440.

THE CLAY MINERALOGY OF THE SHALY PORTIONS OF THE BRASSFIELD LIMESTONE

ERNEST G. EHLERS AND KARL V. HOOVER

Department of Mineralogy, The Ohio State University and Industrial Minerals Section, Ohio Division of Geological Survey, Columbus, Ohio

INTRODUCTION

The Brassfield limestone outcrops over a wide area in southwestern Ohio. It shows considerable variation in physical characteristics, laterally as well as vertically.

The clay minerals associated with this formation have never been examined. It was hoped that a study of these minerals might provide additional information

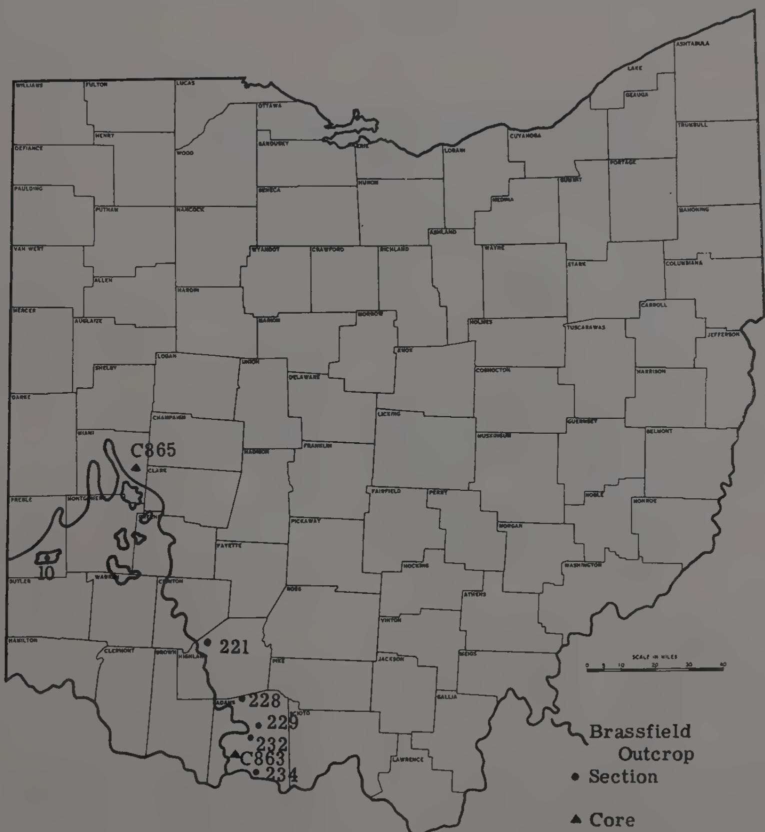


FIGURE 1. Locations of cores and stratigraphic sections.

THE OHIO JOURNAL OF SCIENCE 61(4): 227, July, 1961

on the variable lithology of this formation, and perhaps indicate distinctive differences among the various units.

REGIONAL GEOLOGY

The Brassfield limestone is of Silurian age and is the only formation of the Albion group which outcrops in Ohio. The area of its surface exposure is limited to southwestern Ohio (fig. 1); the outcrop area trends northeastward from the vicinity of Fairhaven, in Preble County, to central Miami County, and thence southeastward to the Ohio River near Rome, in Adams County. The outcrop area of the Brassfield limestone is divided lithologically into northern and southern zones. The boundary between these zones is a covered area in southern Clinton County.

The Brassfield formation is underlain by the Elkhorn formation, which usually consists of red and green shales, although locally it contains quartz or calcite-rich lenses. Stout (1941) reported that the Elkhorn generally contains the minerals sericite, biotite, celadonite, and hematite. Above the Brassfield lies the Dayton formation. This is commonly a bluish-gray silicious calcite-rich dolomite; locally it is a limestone.

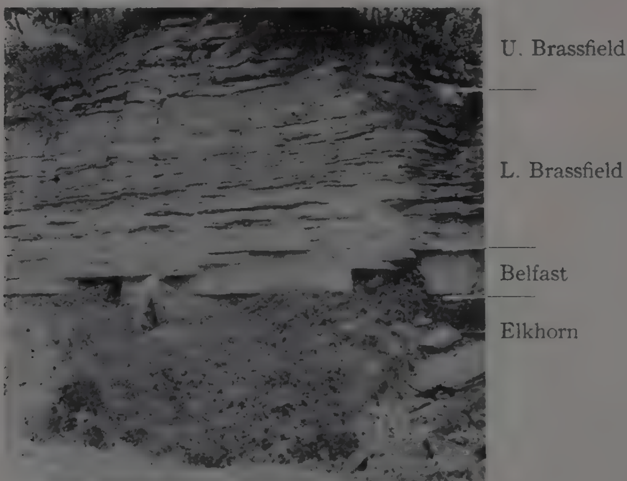


FIGURE 2. Typical Brassfield limestone section in the southern outcrop zone (locality 234).

The Brassfield formation is divided into three stratigraphic units, the Belfast (which is a transitional zone with the Elkhorn), the Lower Brassfield, and Upper Brassfield.

The Belfast unit is a greenish-gray, fine grained argillaceous dolomite or dolomitic limestone. These carbonate beds contain intercalated greenish-gray clay shales, which make up from 3 to 30 percent of the total thickness of 1 to 8 ft. Glauconite, either disseminated or in the form of pellets, is generally present. Sphalerite, pyrite, and chert are locally abundant as accessory minerals. The Belfast unit is considered to be limited to the eastern flank of the Cincinnati arch. In the western outcrop area the correlative bed is a dense limestone or argillaceous

dolomite (0.2 to 1.2 ft thick) which is occasionally present between typical Elkhorn and Lower Brassfield beds.

The Upper and Lower Brassfield units are broken into northern and southern zones by a hiatus in outcrop pattern in southern Clinton County, as well as differences in lithology.

The northern zone of the Brassfield consists of two distinct units—the Lower Brassfield and Upper Brassfield. The Lower Brassfield is typically a light gray to white, fine to coarse-grained crystalline limestone. The crystalline texture is a result of recrystallization of fossil fragments. Green clay is locally present, either in the disseminated state or as thin partings. Bedding varies from thin to massive, with crossbedding common. Field observations indicate that the Lower Brassfield limestone is extremely dolomitic in the Clark County area; the dolomite content decreases gradually in the direction of the Indiana border. In general, the dolomite content also decreases from the bottom to the top of the unit. Pyrite is a characteristic accessory, and sphalerite is locally present in minor quantities.

TABLE 1

Analyses of the shaly portions of the Brassfield limestone

Section no.	Sample no.	Statigraphic unit	Analyses (in percent)			
			CO_3 loss with acid digestion	$CaCO_3$	Newberry $MgCO_3$	Insoluble material
10	14A	Upper Brassfield	——	10.08	2.22	87.70
C865	2A	Dayton	35.20	——	——	64.80
"	6A	"	56.00	——	——	14.00
"	7A	"	45.00	——	——	55.00
"	10A	"	65.15	——	——	93.85
"	22A	Upper Brassfield	63.16	——	——	36.84
"	45A	Belfast	9.30	——	——	90.70
221	10	Lower Brassfield	——	3.12	0.81	96.07
228	10	" "	——	22.56	2.02	75.42
228	10A	Belfast	——	31.20	7.88	61.12
229	17A	Lower Brassfield	——	22.68	4.55	72.77
"	27A	Upper Brassfield	——	3.12	0.61	96.27
"	55A	" "	——	1.32	1.31	97.37
232	12A	Lower Brassfield	——	29.52	6.46	64.02
C863	3	Dayton	——	47.64	34.44	17.92
"	9	"	——	45.36	32.93	21.71
"	11	"	——	45.96	32.83	21.21
"	13	"	——	51.00	35.35	13.65
"	14	"	——	55.92	33.94	10.14
"	16	"	——	56.40	33.33	10.27
"	21	Upper Brassfield	——	90.72	4.44	4.84
"	22	" "	——	89.88	7.27	2.85
"	23	" "	——	91.80	4.34	3.86
"	24A	Lower Brassfield	19.20	——	——	80.80
"	27A	" "	38.24	——	——	61.76
"	28A	" "	22.00	——	——	78.00
"	30	" "	5.52	——	——	94.48
"	31A	" "	19.56	——	——	80.44
"	32A	" "	15.20	——	——	84.80
"	35A	" "	25.46	——	——	74.54
"	44A	Belfast	30.52	——	——	69.48
"	47A	"	26.52	——	——	73.48
"	48A	"	26.28	——	——	73.72
"	51	Elkhorn	24.08	——	——	75.92
234	8B	Lower Brassfield	——	27.48	6.87	65.65

The thickness of the unit varies from a minimum of 6 ft in Preble County to greater than 20 ft in Miami County.

The Upper Brassfield of the northern zone is characteristically a pink, red, or gray, medium to coarse grained bioclastic limestone. Green clay, as partings, lenses, or disseminated material is much more abundant than in the Lower Brassfield. Hematite-rich oolites and fossil fragments are present in Clinton and Greene Counties; this zone grades into a red clay in the extreme northwestern portion of Greene County. Pyrite is present as a characteristic accessory. Glauconite is occasionally present in the upper portions of the unit. The thickness varies from 1 to 22 ft and shows rapid lateral variation. The dolomite content of the Upper Brassfield parallels that of the previously described Lower Brassfield.

The Brassfield limestone of the southern zone has several features which are distinctly different from those of the northern zone. These are the following: lack of sharp lithologic differences between the upper and lower parts, a large

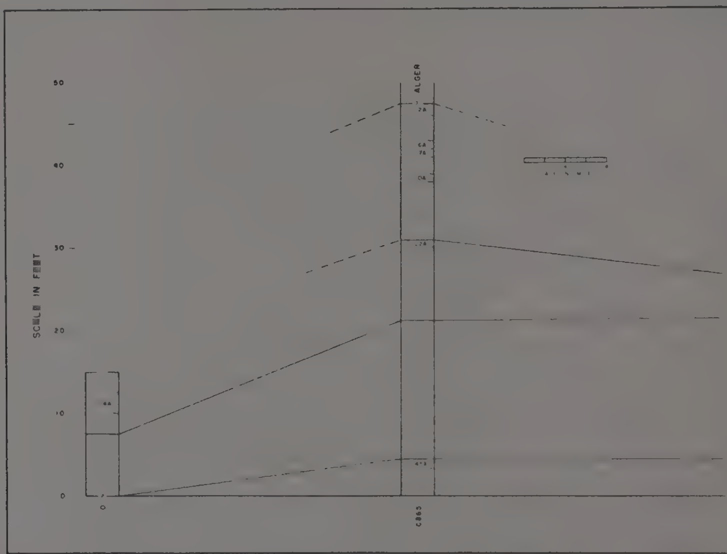


FIGURE 3. Stratigraphic sections and sample locations of the Brassfield limestone.

increase in the shale content, an increase in the number of chert nodules, and differences in many textural and structural features. Although the two rock types of the northern zone do not remain distinct in the southern zone, many of the distinguishing stratigraphic features persist, such as the ferruginous oolite zone, the basal brown limestone, and the course bioclastic texture of the Upper Brassfield.

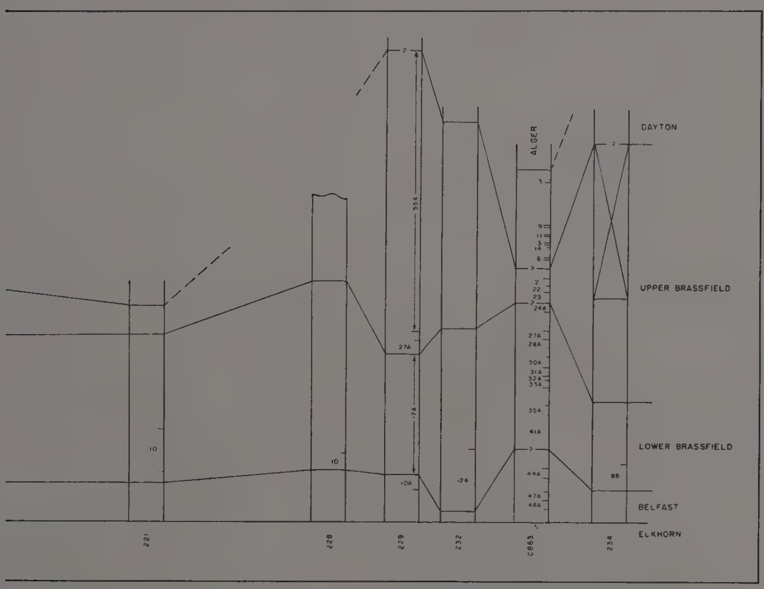
The most common rock type is a light to medium gray, fine to medium grained limestone. The interbedded green shale in some southern exposures constitutes the major portion of the unit (fig. 2), and as in the northern zone, the shale is more abundant in the upper portions. Chert, which occurs near the base, has no fixed stratigraphic position. Glauconite is fairly common throughout the unit, both as discrete beds as well as irregularly-distributed grains. Calcite is prevalent

throughout the unit, with the exception of the West Union area in Adams County, where a large proportion of dolomite is present.

PROCEDURE

Clay samples were collected from thin clay seams in limestone, from both drill cores and outcrops. The type of sample, its locality, and stratigraphic horizon are shown in figures 1 and 3.

The carbonate minerals which occur in abundance within the clay seams were removed by treatment with dilute (1: 3) glacial acetic acid; acetic acid treatment, in contrast to hydrochloric acid treatment, does not appreciably alter the clay-mineral assemblage. The samples were sieved with a 60-mesh screen, weighed, and placed in contact with acid for a minimum of 30 hr. The residue was filtered, given a triple washing with distilled water, evaporated, and reweighed. Newberry



analyses for $CaCO_3$, $MgCO_3$, and insoluble material percentages were run on most of the samples. The results are given in table 1.

Portions of each sample were mounted on glass slides for x-ray studies. Part of the sample was x-rayed by means of a Norelco low angle diffractometer. Copper radiation with a nickel filter was used. The speed was 2° 2θ per min; critical reflections were run at 1° 2θ per min. The area examined ranged from 2.31 to 22.07 Å. All of the significant clay mineral peaks, as well as those of many common impurities fall within this range.

A typical x-ray chart is shown in figure 4. The relative amounts of kaolinite and illite were determined on the basis of intensities of (001) reflections, as suggested by Murray (1953). This technique yields approximate differences in the form of a ratio, but the results are not quantitative.

All of the samples were treated with ethylene glycol in order to determine the presence of montmorillonite, and to observe the nature of the mixed-layer structures. In addition, all samples were rerun after being fired for one hr at 600° C, in order to distinguish between chlorite and other clay minerals, as well as to observe effects on mixed-layer structures.

The results of the x-ray analysis are given in table 2.

DISCUSSION OF RESULTS

Comparison of the Newberry analysis in table 1 with the sample locations clearly shows that the samples collected in the southern zone are richer in insoluble material (mainly clays) than those of the northern zone. It is also interesting to note, when comparing these analyses with the clay-mineral determinations, that

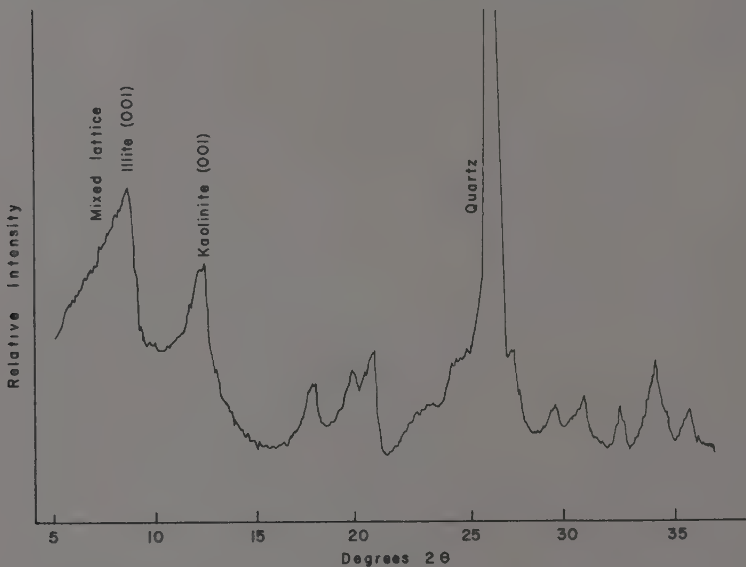


FIGURE 4. Typical x-ray diffractometer pattern (Cu radiation) of a shaly portion of the Brassfield limestone.

the composition of the clays is virtually the same, whether the sample was collected in a clay-rich band, or in a section with a high carbonate content.

As can be noted from table 2, most of the samples collected in the southern part of the outcrop region contain illite and mixed-layer illite-chlorite as the predominant clay minerals, with lesser amounts of kaolinite, and occasional traces of chlorite. The more northern samples contain a similar suite, with the difference that the kaolinite is either absent or present in only trace amounts.

These results are in agreement with similar clay-mineral studies by other investigators. Studies on the clay minerals associated with limestones and dolomites, such as those of Grim, Lamar, and Bradley (1937), Millot (1949), Grim (1951), and Robbins and Keller (1952), indicate that illite is the predominant clay mineral associated with carbonate rocks. Weaver (1958), in summarizing

much of the work done on clay minerals, concluded that although this relationship is correct, illite is also the predominant clay mineral in all sediments and is not noticeably more abundant in limestones than in shales. In most cases where shales and limestones are interbedded, they contain the same type of clay minerals.

Treatment of all samples with ethylene glycol failed to reveal the presence of montmorillonite.

It can be seen from figure 4 that the 10 Å illite peak is noticeably skewed in the direction of the wider spacings. This is often indicative of mixed-layer clay

TABLE 2

Mineral composition of the shaly portions of the Brassfield limestone

Sample number	Illite: kaolinite ratio	Other minerals	Stratigraphic unit
10–14A	Ill., Tr. Kaol.	—	Upper Brassfield
C865–2A	Ill., Tr. Kaol.	—	Dayton
C865–6A	Ill., no Kaol.	Pyr.	"
C865–7A	Ill., no Kaol.	Felds.	"
C865–10A	Ill., no Kaol.	Felds.	"
C865–22A	Ill., no Kaol.	Ill.-Ch.	Upper Brassfield
C865–45A	Ill., Tr. Kaol.	Ill.-Ch., Felds., Pyr.	Belfast
221–10	7	Ill.-Ch., Felds.	Lower Brassfield
228–10	4	Ill.-Ch., Tr. Ch.	" "
229–10A	6	Felds., Tr. Pyr.	Belfast
220–17A	3	Ill.-Ch.	Lower Brassfield
229–27A	6	Ch.	Upper Brassfield
229–55A	5	—	" "
232–12A	3	Ill.-Ch.	Lower Brassfield
C863–3	20	Tr. Ch.	Dayton
C863–9	8	Ill.-Ch.	"
C863–11	12	Ill.-Ch.	"
C863–13	Ill., no Kaol.	Ill.-Ch.	"
C863–14	4	Ill.-Ch.	"
C863–16	13	Tr. Ch.	"
C863–21	13	—	Upper Brassfield
C863–22	11	Ill.-Ch.	" "
C863–23	8	Tr. Ch.	" "
C863–24A	9	Tr. Ch.	Lower Brassfield
C863–27A	7	Tr. Ch.	" "
C863–28A	5	Tr. Ch., Felds.	" "
C863–30A	14	Ill.-Ch., Tr. Ch.	" "
C863–31A	13	—	" "
C863–32A	17	Pyr.	" "
C863–33A	24	—	" "
C863–35A–41A	8	Tr. Ch., Pyr., Felds.	" "
C863–44A	5	Ch.	Belfast
C863–47A	5	Tr. Ch., Pyr.	"
C863–48A	5	Tr. Ch.	"
C863–51	6	Ch.	Elkhorn

Quartz is present in all samples.

Ch. = Chlorite, Felds. = Feldspar, Ill.-Ch. = Illite-chlorite mixed-layer structure, Kaol. = Kaolinite, Pyr. = Pyrite, Tr. = Trace, and Ill. = Illite.

structures. A mixed-layer clay is derived from stripping or degradation of pre-existing clay minerals during weathering; cations removed from the clay structure during weathering are commonly replaced by others, either in the source area or in the basin of deposition, to form a mixed-layer structure. Treatment by ethylene glycol did not produce any broadening or shifting in the peak, indicating that the mixed-layer structure did not contain a clay with an expandable lattice. The shape of the peak either increased in skewness after firing or there was a general increase

in background between 13.8 and 10.5 Å, which is indicative of chlorite in mixed-layer arrangement with illite. This increase in intensity would be expected, as the firing of chlorite minerals which are not in a mixed-layer arrangement increases the intensity of the (001) reflection, as well as depressing the higher order reflections. The increase in intensity over such wide spacings indicates a very random arrangement of Mg or Fe within the structure. Although illite is often in mixed-layer arrangement with montmorillonite, an illite-chlorite mixed-layer structure is relatively uncommon.

The general distribution of illite to kaolinite shows the presence of kaolinite in the southern samples, and either none or merely trace amounts in the northern samples. This relationship appears to hold true for the Dayton formation, and the Upper Brassfield, Lower Brassfield, and Belfast units. Although only a relatively small number of samples have been taken, the consistency of this relationship would indicate that the clay mineralogy does differ in these two areas. Weaver (1958) states that kaolinite tends to be most common in continental and near-shore sediments. It is thus possible that the presence of kaolinite in the southern samples may indicate that this area is closer to the sediment source than the northern samples. This would be in agreement with the much greater abundance of clay in the southern samples.

No significant differences are present in outcrop samples as compared to core samples. For the most part the same clay mineralogy exists among the samples collected from the Dayton, Brassfield, and Belfast units.

CONCLUSIONS

Clay-mineral analyses were conducted on the shaly portions of the Brassfield and adjacent limestones. The predominant clay mineral is illite. Kaolinite, mixed-layer illite-chlorite, as well as trace amounts fo chlorite, were also determined. The results indicate that the more northern samples contain either traces of kaolinite or none at all, whereas those in the south usually contain significant amounts.

REFERENCES CITED

Grim, R. E. 1951. The depositional environment of red and green shales. J. Sedim. Petrol. 21: 226–232.

— — , **J. E. Lamar,** and **W. F. Bradley.** 1937. The clay minerals in Illinois limestones and dolomites. J. Geol. 45: 829–843.

Millot, G. 1949. Relations entre la constitution et la genèse des roches sedimentaires argileuses. Géologie Appliqúee et Prospection Miniére, Univ. of Nancy, 2, 325 pp.

Murray, H. H. 1953. Genesis of clay minerals in some Pennsylvanian shales of Indiana and Illinois. Proc. Second Natl. Conference on clays and clay minerals, Univ. of Missouri, Natl. Acad. Sci. Publ. 327, 47–67.

Robbins, C. and **W. D. Keller.** 1952. Clay and other non-carbonate minerals in some limestones. J. Sedim. Petrol. 22: 146–152.

Stout, W. 1941. Dolomites and limestones of western Ohio. Ohio Geol. Surv. Bull. 42: 468 pp.

Weaver, C. E. 1958. Geologic interpretations of argillaceous sediments. Am. Assoc. Petrol. Geol. Bull. 42: 254–309.

Introduction to Atomic and Nuclear Physics. *Otto Oldenberg.* McGraw-Hill Book Company Inc., New York, Third edition, 1961. 380 pp. $7.95.

The third edition of the author's popular text book follows the pattern of the previous editions. No calculus is necessary. Emphasis is placed on clear simple exposition. Students who may not go on in physics will find the book most helpful in obtaining an understanding of modern concepts in physics.

The third edition considers such new topics as the Van Allen belt, failure of parity, the reality of the neutrino, etc.

For the more serious student a wealth of problem material in a wide degree of difficulty is available with answers. The popularity of the third edition will surely transend that of the previous editions.

MARION POOL

SCIENCE EDUCATION AND THE OHIO ACADEMY OF SCIENCE—AN HISTORICAL REVIEW[1]

RALPH W. DEXTER
Kent State University, Kent, Ohio

At the meeting of the Ohio State University Biological Club on November 3, 1891, President William R. Lazenby suggested, at the conclusion of his presidential address, the formation of a State Academy of Science. He urged that "the initiatory steps toward the founding of such an academy should be taken by this group and tonight." A committee consisting of Prof. Lazenby, as chairman, and Profs. D. S. Kellicott and W. A. Kellerman was appointed immediately to plan an organizational meeting. This was called to order on December 31. Prof. A. M. Bleile was elected chairman and Prof. Lazenby was chosen secretary to serve for this meeting. A committee was selected to frame a constitution and the by-laws. The first set of officers was then elected.

Titles for 26 papers had been submitted for this organizational meeting. Ten were selected for reading while the committees were at work. The Ohio State Academy of Science was created, then, on the last day of 1891. Incorporation was attained on March 12, 1892, with 59 charter members. In 1914 the name was officially changed to The Ohio Academy of Science, a name which had been used for some ten years, unofficially, on most of the Academy publications.

For many years there was no sectional organization, and when sections were established, none was provided for the field of science education until as late as 1940. However, from the very beginning and throughout its long history, The Ohio Academy of Science has been active in promoting science education. In recent years this has become one of its major objectives. This paper will trace the highlights in fostering interest in science education in Ohio over a period of 70 years.

Article II of the original constitution, drawn up in 1891, stated specifically that one objective of the Academy is "to promote the diffusion of knowledge in the various departments of science." One of the papers submitted to be read at the organizational meeting was entitled "Biological Training as Preliminary to the Study of Medicine," written by H. E. Chapin. In the program of the first annual meeting, held in Columbus in 1892, there were three papers dealing with science education. The fourth annual summer field meeting held at Sandusky in 1895 met jointly with the Ohio Teachers Association. Prof. D. S. Kellicott of The Ohio State University informed teachers about the Academy of Science and urged their support in promoting the teaching of science in public schools. At the annual meeting held in Cincinnati that year, a report was given by Dr. E. W. Claypole on "A Mode of Preserving Specimens for Class Use."

At the winter meeting of 1897 held in Columbus, two reports were given on the teaching of science in public schools. In the discussion that followed it was suggested that the Academy publish a circular aimed at improving the teaching of science in the schools. A committee was appointed by President Kellerman (W. G. Tight, E. W. Claypole, and William Werthner), to consider the matter and to report back to the Academy membership. Also, Prof. John S. Royer spoke on the desirability of getting more school men into the Academy. A resolution submitted by J. F. Bliss was adopted which read as follows: "Whereas nature study is rapidly becoming an important feature of the public schools and

[1]This paper was prepared by the Academy Historian for the Science Education Section of The Ohio Academy of Science, meeting at Cincinnati on April 21, 1961.

THE OHIO JOURNAL OF SCIENCE 61(4): 235, July, 1961

whereas the love of nature is the stimulus to all true scientific study, therefore, be it resolved that this Academy of Science requests that the State Agricultural Experiment Station continue to publish bulletins on scientific subjects in terms suited to the juvenile mind."

At the next annual meeting the committee on education reported but little progress. A new committee was then appointed, consisting of W. A. Kellerman, William Werthner, Mary E. Law, J. A. Bownocker, and C. J. Herrick. One of the new committee members, Miss Mary E. Law, had read a paper at this meeting on "A Plea for Science Teaching in the Public Schools." This report was printed in full in the 7th Annual Report of the Ohio State Academy of Science (1899). The following year the committee on science teaching presented a report at the annual meeting held in Cleveland. Much discussion centered around this report, but no record has been left of either the report itself, or any action resulting from it. The printed program listed the following items for discussion: (1) Proportion of time that should be given to science in the high school curriculum. (2) Branches of science to be included and their sequence. (3) Relative time devoted to laboratory and textbook work. (4) The extent that elementary science should be taught in the primary grades. (5) The preparation of teachers for this work.

The summer field meeting of 1900 was held at Put-in-Bay in the month of June. The Academy met with the Ohio State Teachers Association. At the next annual meeting, a member of the Committee on Science Education, William Werthner, read a report entitled, "Modern Language and Science in Ohio High School Courses." Three years later Dr. Edward L. Rice addressed the Academy on "A Statistical Plea for Nature Study."

At the annual meeting of 1904 F. L. Landacre, secretary of the Academy, reported on the work of the Allied Education Association of Ohio. He had been appointed as a member of the executive board of that society, which then extended an invitation to the Academy to participate in a joint meeting. As a result, a special meeting was held in Columbus on December 30 at which time J. C. Hambleton gave a report on "The Relative Value and Extent of Scientific and Literary Teaching in a High School Course," followed by a discussion among those present. The paper was published in the 13th Annual Report of the Academy.

In his presidential address at the annual meeting of 1905, Dr. Herbert Osborn stressed the need for further studies on the natural history of Ohio. He pointed out that such "would fill a sound foundation for the more exact teaching of science in our schools, a branch which is becoming more and more of fundamental importance in education." At this meeting two reports were read on the teaching of science in high schools.

Following a discussion on the value of field trips for students in secondary schools by Prof. George Hubbard at the meeting of 1908, it was voted that a committee be appointed by the president of the Academy to study the matter and report at the next annual meeting. At this same time a new constitution was prepared. Article VII provided for formal sections for the first time as follows: "Members not less than 15 in number may by special permission of the Academy unite to form a section for the investigation of any branch of science. Each section shall bear the name of the science which it represents." A section for science education was not established at that time, but papers and reports of an educational nature were given at frequent intervals at meetings of the established sections.

The presidential address for the meeting of 1912, given by Dr. Bruce Fink, was entitled "Botanical Instruction in Colleges." This was published in full in the *Proceedings of The Ohio Academy of Science* (6, Part 2: 72–87).

The 26th annual meeting of the Academy (1916) was held jointly with the Ohio College Association. The principal address was delivered by Prof. Charles H. Judd of the University of Chicago on "The More Complete Articulation of

Higher Instruction with High Schools." Four additional addresses were given on the general theme of college teaching of science and mathematics. The following year officers and members of the Academy were invited to take part in the Columbus meeting of the Central Association of Science and Mathematics Teachers.

The meeting of 1918 appropriately sponsored a symposium on science and the war. This included a report by E. H. Johnson on "The Newer Demands on Physics and Physics Teachers Due to the War." At the 36th annual meeting a symposium was held on biological training for medicine and dentistry.

An early attempt to stimulate working relations between the Academy and high school science teachers resulted in disappointment. Dr. C. G. Shatzer was appointed in 1929 to investigate ways to encourage interest in science among high school students. Dr. Shatzer wrote in the report that he, as a committee of one, "spent the weeks since its appointment in futile efforts to locate certain high school instructors, who had been reported as particularly interested in this program. These men were not found." He then made two suggestions: first, that a committee be appointed to contact other state academies and summarize their methods used to stimulate scientific endeavor among high school students; second, that the committee assist the membership committee in obtaining more members for the Academy among high school instructors. At this meeting President George W. Rightmire of The Ohio State University delivered an address on "Education in Ohio: The Academy's Part."

At the annual meeting for 1931, the Committee on Junior Scientific Effort reported that the Academies of Science in Iowa, Indiana, and Illinois are also engaged in a similar project. Results from a questionnaire sent to 37 Ohio high schools to get information on science clubs were summarized. Dr. Shatzer then outlined some recommendations for the Academy to follow, including the continuation of such a study by a committee consisting of college administrators and teachers, and high school administrators and teachers.

The following year, Dr. Shatzer reported on continued progress. The outstanding accomplishment was a District Scientific Conference of high school students, which was held in Springfield in 1932. A total of 94 student projects was placed on display, and the Conference was conducted largely under student leadership. This pilot conference was so successful that a recommendation was made to continue the program and to enlarge it wherever possible.

At the same meeting two symposia were held dealing with educational problems. One was entitled, "The Preparation of Students for Graduate Work in Physics," and the other was "An Experiment with the Symposium Method of Teaching."

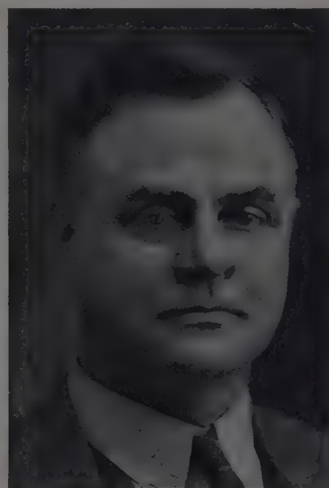
At the annual meeting of 1933, the matter of a science program for secondary school students was discussed. Dr. Shatzer reported that following a conference held with the Director of the Ohio State Department of Education, he wished to propose that a central office be established through which the Academy could communicate to science students in the public schools, and that volunteer service be obtained from members of the Academy to carry out such duties. Also, that specialists among Academy members be asked to cooperate with such a central office in preparing suitable printed material for distribution and to aid students in the identification of specimens which they might collect. A budget of $100 was asked to establish this program. After careful deliberation, the Executive Committee issued the following statement: "That notwithstanding the obvious merits in the Junior Scientific Endeavor Movement as revealed in the fine efforts and report of Dr. Shatzer, it was the unanimous opinion of the committee that due to a lack of funds, to meet and overcome the practical difficulties obviously inherent in the work, as pointed out by Dr. Shatzer, the only thing to do is to hold the matter in abeyance for the present at least." Even though the above proposal failed to materialize, some progress was made in public education by

establishing a series of radio talks in the field of science. This was initiated on January 6, 1933, and Academy members volunteered to participate so that one program was offered each week over a period of time.

At that same meeting a special symposium was held on "Cultural Physics Courses." The following year the sections of physics and chemistry uniting with the Ohio Physics Club sponsored a joint education program. New methods and apparatus for teaching physical science were discussed.

At the annual meeting for 1937, an Invitational Address was given by Dr. Otis W. Caldwell, permanent secretary of the American Association for the Advancement of Science, on "Science and Higher Learning." At this meeting the Section of Chemistry sponsored another special program on educational matters. The following year an invitational address on "The Training of Science Teachers" was given by E. N. Dietrich, State Director of Education. Also at that meeting a special report was given by a committee which had been organized

DR. C. G. SHATZER
Organized the first District Scientific Conference for high school students.



DR. CHARLES W. JARVIS
Organized the first Junior Academy of Science.

the previous year "to cooperate with the Ohio Department of Education in outlining the public requirements in preparing teachers of science for the Ohio junior and senior high schools." The minimum preparation suggested, forty semester hours, was outlined in detail, and it was suggested that a Master's Degree might be completed in the general field of science, rather than in a special department, for secondary teaching.

At the Semicentennial Meeting of the Academy in 1940, a Junior Academy of Science was finally established after the abortive attempt of the previous several years. The Junior Academy was made a Section of the Senior Academy. Prof. Charles W. Jarvis of Ohio Wesleyan University was selected to head this project. A trial Junior Academy meeting was organized as a part of the Semicentennial Celebration, which took place on May 11, 1940. Sixty-five high school students from various parts of the state participated in presenting papers

in the fields of mathematics, physics, chemistry, and biology. A number of demonstrations and exhibitions were also placed on display. The success of this trial meeting assured the establishment of a Junior Academy.

Dr. Jarvis was in charge of the Junior Academy Program and Dr. Otis W. Caldwell spoke to this group on "The Essentials of a Successful Junior Academy." A proposed constitution was presented, officers were elected, and awards were given to those students who were judged best in reading papers and presenting demonstrations.

At the annual meeting for 1941, held in Cleveland, the Junior Academy continued along the lines established the previous year. The annual address for the Junior Academy Section was given by Dean William Westhoger of the College of Wooster. He spoke on "The Function of the Junior Academy in Relation to Science in the Secondary Schools." While the program for the Junior Academy, as well as the Senior Academy, suffered from wartime conditions, both nevertheless continued to operate as best as conditions would allow.

In 1943 Dr. Jarvis gave the principal address for the Junior Academy speaking on "Progress of Junior Academy of Science Work." The following year he spoke on, "The Future of the Junior Academy of Science." A second address was given at that time by Dr. H. H. Rosenberry of Ohio University, who discussed "The Effect of the War on the Future of Science Teaching."

The Academy did not meet in 1945 because of wartime restrictions. The Executive Committee did assemble and, among other things, discussed the possibility of providing a seal for use on certificates given to participants in the Junior Academy Program. Dr. Frederick H. Krecker presented a motion that a committee of three be appointed "to handle the matter of Junior Academy sponsorship."

While the Academy resumed its annual meetings in 1946, the Junior Academy did not meet again until 1948. In the meantime, President Carmean appointed C. H. Bennett, Arthur Harper, and F. H. Krecker, to serve as a committee on the Junior Academy program. Dr. Krecker was named Chairman. At the 1947 meeting he presented a plan prepared by the committee to reorganize and reactivate the Junior Academy.

At the meeting of 1948 held at the University of Toledo a Section of Science Education was organized for science teachers, and the Junior Academy for high school students was reactivated under the sponsorship of the new section. Students taking part in the District and State Science Day exhibitions would become members of the Junior Academy for that year. Dr. Krecker supervised these plans for reorganization. He presided at the meeting at which details for the program were discussed by those in attendance, and he instigated the publication of the *Ohio Academy of Science News*.

The first Annual State Science Day for the Junior Academy under the new plan of operation was held on April 22, 1949, at the meeting held on the campus of Denison University. Students receiving superior rating at the five District Science Day meetings held at the five state universities were invited to participate. Awards were given to students for their accomplishments. Outstanding teachers were honored at the Annual Business Meeting by Dr. Krecker. He also prepared for publication in *The Ohio Journal of Science* (50: 301–304, 1950) an account of the present organization of the Junior Academy, the reason for its existence, and the details of its operation. The section of Science Education at this annual meeting held a panel discussion on "Project Work in the High School Science Groups."

At the annual meeting for 1951, the Conservation Committee recommended to the Academy the promotion of conservation education in the public schools. Also recommended was encouragement for a wider use of field study in the school program.

At the meeting of the Council in 1953, a recommendation from the Executive Committee was approved which provided that the district representatives of the Junior Academy Council and the Executive Secretary of the Junior Academy be appointed by the Executive Committee. Council members would serve for three year terms, and the secretary would serve a five year term. At the program for the Section of Science Education that year, a discussion was held on the "Proposed New Science Section of the Ohio Educational Association and How It May Serve Ohio Science Teachers," led by Dr. J. R. Richardson of The Ohio State University.

In 1954 Prof. R. E. McKay of Bowling Green State University was appointed Executive Secretary of the Junior Academy. Prof. McKay reported a total student participation of 2,268 from grades 7 through 12 for the district meetings and a total registration of 350 for the State Science Day Program. District meetings

DR. FREDERICK H. KRECKER
Reorganized the Junior Academy of Science and founded the *Ohio Academy of Science News.*

were held at seven centers throughout the state. At the meeting of the Executive Committee a lengthy discussion was held on the matter of teacher training and certification. This was stimulated by the publication of an article entitled "New Requirements for Provisional Teaching Certification in Science in Ohio" by Dr. C. E. Ronneberg in ***The Science Teacher*** for March, 1955.

At the meeting for 1956 the discussion on training and certification of science teachers was continued and President Paul Rothemund was authorized to appoint a temporary committee to study the matter. Dr. H. A. Cunningham of Kent State University was named chairman, and he selected a committee of twelve representatives from various disciplines of science and levels of education. That year the student participation in the Junior Academy program rose to 2,673 high school students in seven districts. Approximately 425 took part at the State Science Day Exhibition. The Section of Chemistry sponsored a report on science teacher certification given by Dr. Ronneberg. Also, a guest speaker, Dr. J. R.

Mayor, Director of the Science Teaching Improvement Program of the American Association for the Advancement of Science, spoke to Academy members on "Responsibility of Scientists and Science Departments for the Science Program of Secondary Schools."

The following year participation in the Junior Academy reached the level of 3,556 students in the seven District Science Day Meetings. Of these, 620 were invited to take part in the Ninth Annual State Science Day Program. Because of other pressing duties, Prof. McKay requested that he be replaced by Prof. G. G. Acker as Executive Secretary of the Junior Division, but Prof. McKay agreed to serve as Assistant Executive Secretary. At the meeting of the Section of Science Education, Dr. Cunningham reported on "Some Challenging Problems in the Training and Certification of Elementary and High School Teachers," and Dr. Ronneberg reported to the Section of Chemistry on "Needed Changes in Certification of Science Teachers."

The following year a special lecture, "Federal Program for Improving Science Education," was presented by Dr. Bowen C. Dees, Deputy Director of the National Science Foundation. This lecture was sponsored by the Section of Physics and Astronomy. A total of 877 high school students from 233 schools took part in the State Science Day Program. These students had been selected from 4,434 students taking part in the Tenth Annual District Science Day Meetings. A final report of the special committee on the training and certification of science teachers was given, and the Section of Chemistry sponsored that year a symposium on "Trends and Problems in the Teaching of General Chemistry."

In 1959 a new committee was established to continue the study of training and certification of science teachers with Dr. J. C. Gray of Western Reserve University as Chairman. That year, for the first time, the number of projects permitted entry at the State Science Day Exhibition was limited to 600 because of its rapid growth in recent years, and the limitation of available space. A Science Day Award was presented for the first time to those schools from which many students earned a superior rating.

The Section of Geography sponsored a panel discussion on "The Status of Geography in our Secondary Schools" at the Annual Meeting for 1960. A total of 600 projects in which nearly 700 students from 240 schools, representing nine Science Day Districts, were judged during the Junior Division Exposition. At the Annual Meeting, in addition to awards given to outstanding students, teachers, and schools, Prof. Acker presented a Distinguished Service Citation to Dr. Frederick H. Krecker for his eminent service in reviving and guiding the program of the Junior Division. Two of the outstanding Academy accomplishments for this year were the receipt of funds from the National Science Foundation to operate the Science Day Program in Ohio, and to establish a Visiting Scientist Program for Ohio schools. With substantial funds from this source, giving national recognition to the educational program of The Ohio Academy of Science, this organization has come of age as an effective body for the promotion of science education in the state of Ohio.

Acknowledgment is made to the following officers of The Ohio Academy of Science for a careful reading of the manuscript: Dr. Glenn H. Brown, President; Dr. George W. Burns, Secretary; and Kenneth B. Hobbs, Executive Secretary.

ANNUAL REPORT OF THE OHIO ACADEMY OF SCIENCE

1961

Organized 1891 — Incorporated 1892

Affiliated with the American Association for the Advancement of Science

OFFICERS AND COMMITTEES FOR 1961

President
Guy-Harold Smith

President-Elect
Kenneth C. Caster

Secretary
George W. Burns

Treasurer
Robert M. Giesy, III

Director of Public Relations
——————

Executive Secretary
Kenneth B. Hobbs

Director, Junior Academy
George G. Acker

Executive Vice-Presidents

A. *Zoology:* L. S. Putnam
B. *Plant Sciences:* W. G. Gambill
C. *Geology:* Jane Forsyth
D. *Medical Sciences:* E. W. E. Schear
E. *Physics and Astronomy:* C. A. Randall
K. *Genetics:* E. F. Paddock
F. *Geography:* E. H. Bush
G. *Chemistry:* R. G. Johnston
H. *Science Education:* Phyllis Read
I. *Anthropology and Sociology:* Dwight G. Dean
J. *Conservation:* R. B. Redett

Membership Vice-Presidents

A. *Zoology:* E. E. Dickerman
B. *Plant Sciences:* Knut J. Norstog
C. *Geology:* Floyd Nave
D. *Medical Sciences:* John Bartone
E. *Physics and Astronomy:* E. L. Jossem
K. *Genetics:* R. G. Jaap
F. *Geography:* William Harris
G. *Chemistry:*
H. *Science Education:* Mildred Bowman
I. *Anthropology and Sociology:* J. K. Balogh
J. *Conservation:* E. E. Good

COMMITTEES

Executive
G.-H. Smith, *Chm.*, G. G. Acker, J. K. Balogh, G. H. Brown, G. W. Burns, R. M. Giesy, R. A. Popham

Nominating
Members of the Executive Committee

Program
Executive Vice-Presidents and the Secretary, *Chairman*

Library
Academy Librarian, Mary D. McCoy, *Chairman*
W. G. Gambill..........Term expires 1963
Jacob Verduin..........Term expires 1965

Publications
G. W. Burns....................*Chairman*
W. G. Gambill..........Term expires 1963
Jacob Verduin..........Term expires 1965

Trustees of Research Funds
E. H. Cherrington, *Chm.* Term expires 1962
R. Davidson............Term expires 1963
H. C. Eyster...........Term expires 1964

Necrology

H. H. M. Bowman, *Chm.*..Term expires 1962
W. C. Stehr............Term expires 1963
J. T. Maddox...........Term expires 1964

Resolutions

J. H. Cooper, *Chm.*.......Term expires 1962
A. Lindschied...........Term expires 1963
W. Singer...............Term expires 1964

Ohio Flora

T. R. Fisher, *Chairman*
E. L. Braun
J. A. Herrick
G. W. Blaydes
E. S. Thomas
Clara Weishaupt

Academy History

R. W. Dexter, *Chairman*

Training and Certification of Science Teachers

C. A. Randall, *Chairman*
E. H. Bush
R. P. Goldthwait
E. E. Good
A. G. McQuate
J. Skilken
T. C. Holyoke

Institution and Corporation Membership

E. F. Paddock, *Chairman*
G. H. Crowl
S. N. Halleck, II

Academy Representatives

1. On the Joint Administrative Board of The Ohio Journal of Science:
W. G. Gambill......Term expires 1963 Jacob Verduin......Term expires 1965

2. On the Council of the American Association for the Advancement of Science:
G. H. Smith, G. H. Brown (alternate)

The Council for 1961–62

Acker, G. G.
Balogh, Joseph K.
Bartone, John
Bowman, H. H. M.
Bowman, Mildred
Brown, Glenn H.
Burns, G. W.
Bush, Everett H.
Caster, Kenneth C.
Cherrington, E. H.
Coash, John
Cooper, J. H.
Dean, Dwight G.
Dexter, R. W.
Dickerman, E. E.
Eblin, Lawrence P.
Fisher, T. Richard
Forsyth, Jane
Gambill, W. G.
Giesy, Robert
Good, E. E.
Harris, William
Jaap, R. George
Johnston, Robert G.
Jossem, E. Leonard
McCoy, Mary D.
Nave, Floyd
Norstog, Knut J.
Paddock, Elton F.
Plaine, Henry L.
Popham, Richard A.
Putnam, L. S.
Randall, Charles A.
Read, Phyllis
Redett, Robert B.
Rothemund, Paul
Schear, E. W. E.
Smith, Guy-Harold
Verduin, Jacob

REPORT OF THE SEVENTIETH ANNUAL MEETING OF THE OHIO ACADEMY OF SCIENCE

The 70th annual meeting was held on the campus of the University of Cincinnati April 20, 21, and 22, 1961, the fifth to have been so located. Previous meetings of the Academy held in Cincinnati were in 1895, 1905, 1928, and 1939. A total of 685 persons registered for the meetings of the senior division. The local committee on arrangements, under the chairmanship of Dr. William A. Dreyer, did an outstanding job in providing facilities to make this meeting a real success.

The Executive Committee, the Council, and the Committee on Election of Fellows met on April 20; their reports are found elsewhere in this Annual Report. On Friday, April 21, the eleven sections met with the presentation of some 150 research papers and symposia. Field trips were conducted by the sections of Geology and of Geography.

Throughout Friday the Junior Division sponsored the thirteenth Annual State Science Day, in which 657 projects were entered by nearly 700 students from the high schools of the state. Sectional meetings of the Senior Division were suspended at 11:00 AM to permit viewing and judging of these exhibits.

The annual banquet and business meetings were held Friday evening in the Great Hall of the Union, with Dean Charles K. Weichert serving as toastmaster. President Walter C. Langsam extended official greeting from the University of Cincinnati, and the response was made by Dr. Dwight DeLong, most recent past-president of the Academy. Dr. Glenn H. Brown, President of The Ohio Academy of Science, delivered the presidential address, "Structure of Liquids and Solutions." Professor G. G. Acker, Director of the Junior Academy, announced awards to outstanding high school teachers as well as the Krecker awards to seven schools. At the business meeting, officers were elected for the coming year, as listed at the opening of this report. A constitutional amendment, changing the title of the Executive Secretary of the Junior Division to Director of the Junior Division, was unanimously approved. Forty members of the Academy were announced as newly elected Fellows. Their names and sectional affiliations follow:

A—Richard Dale Alexander
C—Richard J. Anderson
J—John Edward Aughanbaugh
B—Dwight H. Berg
A—Robert Bieri
A—A. S. Bradshaw
A—Alfred Carter Broad
A—Joseph Harvey Camin
B—Tom S. Cooperrider
G—Joseph Milton Denham
A—Ray Thomas Everly
J—Ollie Edgar Fink
C—George J. Franklin
A—James C. Gray
G—Herschel G. Grose
A—Howard William Hintz
C—John R. Hyland
C—William F. Jenks
A—Emerson Kemsies
A—Edward J. Kormondy
C—Heber D. Lessig
B—Percy Lane Lilly
K—Morley Gordon McCartney
A—W. C. Myser
B—J. Gordon Ogden, III
J—Hayden Whitney Olds
H—Joseph A. Ralston
A—Roy Wilson Rings
D—Henry Zodoc Sable
C—George M. Schafer
C—David M. Scotford
H—Naomi Snyder
G—Howard A. Tanner
A—Charles A. Triplehorn
A—Andrew Albert Weaver
H—William Weaver
A—Howard Vincent Weems, Jr.
G—Bruce V. Weidner
A—Robert W. Winner
B—Warren Arthur Wistendahl

Respectfully submitted,

George W. Burns, *Secretary*

REPORT OF THE EXECUTIVE COMMITTEE AND THE COUNCIL

The Executive Committee met June 11, August 26, September 24, October 29, December 2, 1960, January 21, 1961, February 25, April 4, and April 20; the Council met December 2 and April 20.

1. *Meetings of the Executive Committee.*—In addition to much routine business incident to the operation of the Academy and planning long-range programs, the Executive Committee: authorized subscription to a news clipping service on an experimental basis, received a $23,000 grant from the National Science Foundation for the second year's operation of the Visiting Scientists' Program, appointed Dr. W. A. Manuel of Delaware, Ohio, for a second year as Director of that program, with the devoted work of the Ohio Flora Committee saw the publication of "Woody Plants of Ohio," effected sectional affiliation with the Ohio College Association, received a grant of $15,000 from the Kettering Foundation toward 1961 operation of the Academy, and eliminated the $1.50 half-year dues for new members.

2. *Meetings of the Council.*—Reports were made by all officers and most committee chairmen; their annual reports are presented in the pages following.

Council approved presentation to the membership of a constitutional amendment changing the title of the Executive Secretary of the Junior Division to Director of the Junior Division, and approved a recommendation of the Executive Committee that the annual dues be changed to $6.00 effective January 1, 1962 (student dues remaining at $3.00).

Respectfully submitted,

George W. Burns, *Secretary*

REPORT OF THE EXECUTIVE SECRETARY

During the twenty-three months of operation of the Central Offices of the Academy in Columbus, individual membership of the Academy has grown from approximately 1100 to more than 1800 members. In 1959, the Academy listed 29 Corporation-Institution members which were at the time paying annual dues of $25.00. As of May 1, 1961, the Academy has 25 Corporation-Institution members which pay $100.00 per year. These members are listed annually in the November issue of The Ohio Journal of Science.

The Academy has received from the National Science Foundation a $7,000 grant for the operation and development of Science Days in Ohio and a $23,000 grant for the second year of operation of the highly successful Visiting Scientists Program.

Respectfully submitted,

KENNETH B. HOBBS, *Executive Secretary*

REPORT OF THE TREASURER
FISCAL YEAR 1960

EXHIBIT A. COMPARATIVE STATEMENT OF FINANCIAL CONDITION
As of December 31, 1960 and 1959

ASSETS

	1960	*1959*	*Increase (Decrease)*
CURRENT EXPENSE FUND:			
Cash in Huntington National Bank	$ 7,083.00	$ 887.97	$ 6,195.03
Savings accounts:			
Buckeye Federal Savings & Loan Association	0.00	5,000.00	(5,000.00)
Franklin Federal Savings & Loan Association	0.00	5,000.00	(5,000.00)
Ohio Federal Savings & Loan Association	0.00	5,000.00	(5,000.00)
Park Federal Savings & Loan Association	0.00	1,000 00	(1,000.00)
Investments:			
Modern Finance Co. certificates	20,000.00	8,000.00	12,000.00
Aldens, Inc. stock	5,018.88		5,018.88
Aldens, Inc. bonds	908.00		908.00
American Telephone & Telegraph Co. stock	300.00		300.00
BancOhio stock	566.64		566.64
Economy Savings & Loan Co. certificates	15,000.00		15,000.00
Total Current Expense Fund	$48,876.52	$24,887.97	$23,988.35
RESEARCH FUND:			
Cash in Huntington National Bank	0.00	213.08	(213.08)
U. S. Savings bonds—Series G	0.00	200.00	(200.00)
BancOhio stock	0.00	541.44	(541.44)
First Federal Savings & Loan Association	0.00	1,478.93	(1,478.93)
Total Research Fund	$ 0.00	$ 2,433.45	$(2,433.45)
TOTAL ASSETS	$48,876.52	$27,321.42	$21,555.10

LIABILITIES AND NET WORTH

	1960	*1959*	*Increase (Decrease)*
LIABILITIES:			
Dues collected in advance	$ 0.00	$ 45.00	$ (45.00)
Research Fund	2,741.95	2,433.45	308.50
National Science Foundation grants:			
# 9232	8,846.14	6,467.62	2,378.52
9714	2,118.28	2,118.28	0.00
12396	17,117.44		17,117.44
12442	3,875.92		3,875.92
Total Liabilities	$34,699.73	$11,064.35	$23,635.38
NET WORTH:			
Current Expense Fund	14,176.79	16,257.07	(2,080.28)
Total New Worth	14,176.79	16,257.07	(2,080.28)
TOTAL LIABILITIES AND NET WORTH	$48,876.52	$27,321.42	$21,555.10

EXHIBIT B. STATEMENT OF REVENUE AND EXPENDITURES
For the year ended December 31, 1960

Current Expense Fund:		
Revenue:		
Membership dues:		
Individuals	$ 4,234.50	$
Corporations and institutions	2,047.00	6,281.50
Gifts:		
Kettering Foundation	15,000.00	
Others	440.75	$15,440.75
Junior Academy		1,644.90
Interest earned:		
Savings accounts	282.00	
U. S. Savings bonds	2.50	
U. S. Treasury bills	8.87	
Modern Finance Company certificates	370.00	
F.N.M.A. bonds	883.12	1,546.49
Other income:		
Exhibit space rental	175.00	
Special paper sale	7.71	
Dividends from stock	19.25	
N.S.F. Grants—administration fee	1,486.71	1,688.67
Total Revenue		$26,602.31
Expenditures:		
Postage	495.93	
Brochures and programs	848.74	
Engraving and printing	1,030.95	
Office supplies and expense	2,698.17	
Advertising	210.25	
Telephone and telegraph	566.60	
Salaries—executive secretary and clerical	12,152.00	
Payroll taxes	246.06	
Part-Time labor and services	749.31	
Travel expense	439.09	
Speakers	75.00	
Outstanding teacher awards	56.00	
Honorariums	400.00	
Auditing expense	75.00	
Academy conference and meeting	74.00	
Newsletter	2,005.94	
Ohio Journal of Science	3,441.23	
Junior Academy	337.90	
Office equipment purchased	2,280.42	
Total Expenditures		28,682.59
Excess of Expenditures Over Revenues		(2,080.28)
Research Fund:		
Revenue:		
American Association for Advancement of Science grant		$ 650.00
Interest earned		150.00
Dividend income		58.50
Total Revenue		$ 858.50
Expenditures:		
Robert W. Long—grant	$ 200.00	
T. Richard Fisher—grant	200.00	
Janet P. Toy—grant	150.00	
Total Expenditures		550.00
Excess of Revenue Over Expenditures		$ 308.50

Respectfully submitted,

Robert M. Giesy, *Treasurer*

REPORT OF THE ACADEMY LIBRARIAN

	1959–60	1960–61
Foreign Exchanges	419	410
Domestic Exchanges	129	135
Grand Total	548	545
New Exchanges:		
Foreign	17	12
Domestic	2	9
Dropped:		
Foreign	20	3
Domestic	7	3
Special Papers Sold (Number)	?	43
Revenue	$5.15	$46.33

Monies from the sale of "Special Papers" were turned over to Dr. Robert Giesy, Treasurer of the Academy.

Respectfully submitted,

(Mrs.) Mary D. McCoy, *Librarian*

REPORT OF THE JOINT ADMINISTRATIVE BOARD OF THE OHIO JOURNAL OF SCIENCE

The annual meeting of the Joint Administrative Board of The Ohio Journal of Science was held at Columbus on April 8, 1961. The meeting was called to order by Board Chairman Gambill. Present were Dr. R. L. Bates and Dr. R. H. Davidson, representing The Ohio State University; Dr. W. G. Gambill, representing The Ohio Academy of Science; as well as Dr. H. L. Plaine and Dr. R. A. Popham of The Ohio Journal of Science staff. Dr. Warren P. Spencer was unable to attend.

Minutes of the last meeting were approved as read.

Dr. W. G. Gambill was re-elected chairman of the Board for the year 1961–62.

The report of the Business Manager was approved as read. This report, which accompanies these minutes, is mainly in the form of a financial statement for Volume 60. Dr. Popham reported that (1) circulation of the Journal increased to 2,454 during the year as compared to 2,030 a year ago, (2) the total average cost per page for publishing the Journal in 1960 increased to $20.00, as compared to $17.55 a year ago, and that (3) the Journal will probably be able to operate during 1961 on its regular sources of revenue.

The report of the Editor, Dr. Plaine, was approved as read. A copy of this report is attached to these minutes. The Editor indicated that the Journal is about 3 months behind in the publication of papers. This delay in the publication of papers is considered to be somewhat less than optimum, and represents an opportunity for exceptionally prompt publication of papers.

The following staff members were re-elected for the year 1961–62; Dr. Plaine, Editor; Dr. Popham, Business Manager. After his appointment, Dr. Plaine announced the reappointment of Dr. T. H. Langlois as Book Review Editor. Dr. Plaine indicated his willingness to serve as editor at least until April 1, 1963.

During a period of discussion, it was decided that the present reprint order forms, which have been a constant source of confusion, should be revised by the Business Manager and submitted by mail to members of the Joint Administrative Board for their approval. Due to a considerable increase in the amount of work in the Business Manager's office, resulting from a rapid increase in circulation of the Journal, the Business Manager was authorized to procure supplementary help as needed, the help to be paid for on an hourly wage basis. The Business Manager was also authorized to use his discretion in loaning sums of money, for short periods of time, to the Treasurer of The Ohio Academy of Science on an interest-free basis.

The Editor was granted permission to print the index for each volume in the first issue of the following volume. This represents a change from the present procedure of printing the index in the last issue of each volume. The Editor was also granted permission to index all new species under one index heading (New Species). This represents a departure from the present procedure of indexing each new species alphabetically in the general index. The Board granted the Editor authority to require abstracts from authors contributing to the Journal. It was stressed in the discussion concerning this authorization that the abstract must be meaningful and in specific terms in order that a person reading the abstract may obtain the principle ideas set forth in the paper. It was further agreed that if the Editor requires abstracts of authors, he should be critical of these abstracts, and if they do not meet a high level excellence, they should be returned to the authors for revision.

The matter of the need for an Associate Editor was discussed at length. It was pointed out that in cases of emergency, death, illness, or excessive workloads, the Journal, at the present time, is left with no one who is sufficiently familiar with the procedures and state of affairs in the Editor's office to take over his duties. The Board agreed that an Associate Editor should work under the direction of the Editor participating in all of the editorial chores, in order that he may have full knowledge of the status of each manuscript and the stage of development of each issue of the Journal. At the conclusion of this discussion, the members of the Joint Administrative Board agreed that an Associate Editor should be appointed. Dr. Gambill instructed all members of the Board to begin at once to look for a man who has the capabilities and desire to fill such an office.

There being no further business, the Board adjourned.

Respectfully submitted,

RICHARD A. POPHAM, *Secretary of the Board*

THE OHIO JOURNAL OF SCIENCE

VOLUME 60—FISCAL YEAR 1960

BALANCE SHEET

	Vol. 59 Fiscal Year 1/1/59 12/31/59	Vol. 60 Fiscal Year 1/1/60 2/12/61
RECEIPTS:		
Bank balance at beginning of period	$ 3,230.08	$ 2,686.20
O.S.U.—paid for subscriptions	2,750.00	3,000 00
O.A.S.—paid for subscriptions	2,150.00	2,292.50
Non-members—paid for subscriptions	739.00	755.00
Separate numbers, volumes and reprints sold	430.36	759.60
50 year index sold	15.00	0.00
O.A.S.—paid ½ cost of plates	227.99	429.35
O.A.S.—paid for annual report	191.16	219.38
Miscellaneous	1,062.60	187.80
Advertisements	406 38	637.61
O.A.S.—gift	0.00	500.00
	$11,202.57	$11,467.44
EXPENDITURES:		
Spahr and Glenn—printing O.J.S.	$ 5,824.57	$ 6,174.96
Engraving—plates	858 70	917 07
Postage and express	248.34	278.90
Labor	283.50	4.75
Editor's office	0.00	338.27
Office expenses and bank charges	26 77	28 44
Advertising of the O.J.S.	0.00	15.00
Reprints	53.37	74.65
Mailing envelopes	0.00	360.05
Refunds	0.00	6.50
Miscellaneous	1,221.12	42.45
Bank balance at end of period	2,686.20	3,226.40
	$11,202 57	$11,467 44

THE OHIO JOURNAL OF SCIENCE

REPORT OF THE EDITOR OF VOLUME 60, 1960
to the Joint Administrative Board

Volume 60 of The Ohio Journal of Science contained 408 pages, of which 344 pages were devoted to 49 scientific papers in 9 areas (as designated by sections of The Ohio Academy of Science); 21 pages were devoted to affairs of the Academy; 16 pages to advertising; and 27 pages to announcements, book notices, the index and table of contents, and routine journal format. Thirty-two book notices were published during the year. The Symposium, "Problems Resulting from Population Growth," sponsored by the Conservation Section, was published in the July issue. Thirty per cent of the published papers originated at The Ohio State University; forty-one per cent were from other sources within the state; and twenty-nine per cent came from sources outside Ohio.

We wish to thank the various members of the Academy, as well as our several colleagues who are not members, for their generous service as reviewers or referees.

Respectfully submitted,

HENRY L. PLAINE, *Editor-in-Chief*

Distribution by Field of Articles Published in 1960

Field	No. of articles	Total pages	Percent
Anthropology and Sociology	1	10	2.9
Chemistry	6	40	11.6
Conservation	2	40	11.6
Geology	7	63	18.3
Physics and Astronomy	2	21	6.1
Plant Sciences	11	61	17.8
Science Education	1	3	0.9
Zoology	18	98	28.5
Genetics	1	8	2.3
	49	344	100.0
Other			
Notices			
Academy	7	6	
Book	32	6	
Annual Report of Ohio Academy of Science		15	
Table of Contents		4	
Index		2	
Advertising		16	
Journal Format		15	
Number of pages		64	
Total number of pages in volume 60:		408	

REPORT OF THE DIRECTOR OF PUBLIC RELATIONS

Although the results have not been tabulated at this time, and cannot be until the end of the year, perhaps the most important thing done in this field this year was a subscription to a news clipping service. This should provide valuable information on the type and timing of news releases.

Perhaps of equal importance has been the work of the Executive Secretary, Kenneth Hobbs. Most of the contacts during the year have been made by him, not only with news outlets, but with any person or organization interested in the Academy.

Although news sources are interested in the work of the Academy, we cannot supply them with information if we have none. This year only 4 of the 11 sections supplied the Director with abstracts, for example. It is up to the members, and particularly to the officers of the Academy, to supply possible news material whenever possible.

Although the present Director has allowed his name to be presented for re-election, he is forced to resign at the end of the present school year due to other pressures. The four years in this office have been enlightening and encouraging in terms of progress within the Academy as a whole. As far as the publicity for the annual meeting is concerned—and this, along with serving on the Executive Committee, is the major job of the Director of Public Relations—a procedure has been established so that any successor will at least have a form to follow until he gets his feet on the ground.

JOHN R. COASH, *Director of Public Relations*

REPORT OF THE EXECUTIVE SECRETARY OF THE JUNIOR ACADEMY THE OHIO ACADEMY OF SCIENCE

Junior Academy activities for the year 1960–61 were supported in part by a grant in the amount of $6800 received from the National Science Foundation. Funds from this grant were used to augment services provided by the Central Office and by the Executive Secretary, Junior Academy, to Academy sponsored programs throughout the state. In addition the Executive Secretary, Junior Academy, was provided with secretarial assistance without which efficient operation would have been impossible. Communication with subsidiaries (districts) and affiliates (local science days) was improved by numerous visitations and an increased number of mailings. An attempt to establish uniformity in judging criteria and procedures was begun by furnishing standard judging cards to all affiliated science days.

Data have been accumulated for a Directory of Science Days in Ohio. The data will be published in mimeograph form about July 1, 1961.

A Handbook of Science Days is scheduled to go to press about September 1, 1961.

Partial support for 1961–62 operations has been granted by the National Science Foundation.

Section I Organization

A. *Mohican District:* The first annual District Science Day was held on April 8 at Ashland College under the direction of Dr. Milton Puterbaugh, Chairman of the Chemistry Department and Mr. James McDowell, Ashland High School. Five hundred (500) students from 29 schools participated in this event. Strong active support given the committee by President Glenn L. Clayton and the administration, faculty and students of Ashland College contributed substantially to the initial success of the new district.

B. *West District:* Wittenberg University asked to be relieved of responsibility for District Science Day and a new district center was established at Central State College, Wilberforce. Dr. E. O. Woolfolk, Chairman of the Chemistry Department and Karl Braun, Keifer Junior High School, Springfield served as councilmen for the district. Enthusiastic participation by Dr. Woolfolk and members of the administration, faculty and student body of Central State College and the generous hospitality of President Charles Wesley aided greatly in the efficient operation of the first science day.

C. *Central District:* District Science Day was returned to the Ohio State University campus after three years at the State Fairgrounds. Councilmen, Dr. Earle Caley, Department of Chemistry, and Mr. Robert McBurney, Worthington High School were aided by active university and high school committees. President Novice Fawcett authorized the use of The Ohio State University Fieldhouse for the event. Ample space was provided for the six hundred (600) projects chosen from the top ranking students at the local science days.

D. *Special Committees:*

A. Dr. A. G. McQuate, Department of Biology, Heidelberg College is serving as chairman of the committee appointed to study the problem of selection of outstanding teachers. The committee will report its findings at the October 1961 meeting of the Junior Academy Council.

B. The committee on judging, Robert E. McKay, Bowling Green State University, chairman, will present a formal report of its findings to the October meeting of the Junior Academy Council.

Section II Affiliated Local Science Days

The 126 affiliated local science days represents an increase of 45 during the past year. More than 300 schools are represented in these organizations and include participation by all grades from kindergarten through 12th. Reports have been received from 82 of the affiliates representing 201 schools. These reports indicate that more than 88,000 persons observed projects presented by 12,669 students.

Section III District Science Days

More than 6100 students from 548 schools presented projects at the ten District Science Days.

Several procedures for reducing the number of participants were adopted by the individual district planning committees. These procedures include:

A. 7th or 8th grade projects not permitted
B. Joint projects not permitted
C. School quotas for 7, 8, and 9th grades
D. School quotas for all grades
E. Compulsory elimination at local school or county level.

DISTRICT SCIENCE DAY DATA

		No. of Projects	No. of Students	No. of Schools
March 25,	East, Muskingum College	269	285	25
	West, Central State College	536	612	56
April 1,	Northeast, Kent State University	770	770	90
	Central, Ohio State University	621	625	71
April 8,	Southeast, Ohio University	519	574	41
	North Central, Heidelberg College	971	971	66
	Southwest, Miami University	556	671	72
	Northwest, Bowling Green State U.	818	818	69
	North, The Defiance College	244	244	20
	Mohican, Ashland College	500	500	29
		5804	6070	548

Section IV State Science Day

The planning base for the 1961 State Science Day at the University of Cincinnati was 640 projects (600 to established districts and 40 to Mohican District). Quotas were based upon the number of participants (9–12 grades) at the 1960 District Science Days. The 657 registered projects will be exhibited in the field house (581) and in the Chemistry Building (76). Student papers will be read at an open meeting in the Biology Building. Judging will be accomplished at 11:00 with sectional meetings being suspended for that purpose.

Section V Ohio Academy of Science News

Mrs. Clara Kenney, Chillicothe, served as editor for Volume XIII of the Ohio Academy of Science News. Four issues containing a total of 32 pages were printed and distributed to more than 10,000 readers. The increased space was necessary in order to provide adequate coverage for the Visiting Scientist Program. An attempt to secure advertising for the News was not productive as only one advertisement was published. Scattered reports indicate increasing interest in this publication.

Section VI Scholarship Tests

Mr. William Zeitler, Columbus, has announced that new tests will be administered by the testing service of the University of Cincinnati.

Section VII Outstanding Teacher Awards

The following have been selected to receive an outstanding teacher award in their respective districts:

Southeast —Ralph R. Walker, Logan High School, Logan
East —Sister Mary Veronica, Sacred Heart School, Coshocton
Northeast —Theodore Cunningham, Lakewood High School, Lakewood
North Central—Floyd R. West, Sulphur Springs High School, Sulphur Springs
Central —John R. Coontz, Marion-Franklin High School, Columbus
Southwest —Sister Mary Joseph, RSM, Mother of Mercy High School, Cincinnati
West —Frederick L. Dafler, Franklin-Monroe High School, Pitsburg
Northwest —George Clark, Archbold High School, Archbold
North —did not select
Mohican —not reported

Section VIII School Awards

Frederick H. Krecker Awards each consisting of an engraved plaque and a cash stipend of $150.00 will be presented to the following schools:

Southeast —Jackson High School, Jackson
East —no qualified applicant
Northeast —Austintown-Fitch High School, Youngstown
North Central—Marion Catholic High School, Marion
Central —University High School, OSU, Columbus
Southwest, —Eaton Exempted Village School, Eaton
West —Keifer Junior High School, Springfield
North —Napoleon High School, Napoleon
Northwest —Notre Dame Academy, Toledo
Mohican —not organized in 1960

Section IX State Science Day Awards

Plaques signifying excellence of projects presented at the 1960 State Science Day were awarded to:

Eaton Exempted Village School (Southwest)
Fairborn High School (West)
Bryan High School (North)

Registrations for the 1961 State Science Day indicate that 32 schools are eligible to compete for the award.

Section X Personnel

The following changes in personnel on the Council of the Junior Academy were made:

District Councilmen:

Southeast —C. I. McClure, Marietta High School
East —W. Hughes Barnes, Dept. of Geography and William Adams, Dept. of Biology, Muskingum College
Northeast —Miss Betty Olmstead, Northfield-Macedonia High
Central —Dr. Earle Caley, Dept. of Chemistry, OSU and Robert McBurney, Worthington High School

Southwest—Mrs. Lillian McElroy, Mariemont High School
West —Dr. E. O. Woolfolk, Dept. of Chemistry, Central State
Northwest—Albert Siekeres, Fostoria High School
North —Mr. Robert Neff, Dept. of Physics, The Defiance College
Mohican —Dr. Milton Puterbaugh, Dept. of Chemistry, Ashland College and Mr. James McDowell, Ashland High School

Section XI Miscellaneous

Owens-Illinois Glass Company, Toledo, donated 675 sets of souvenir glasses for distribution to State Science Day participants.

Executive Secretary Junior Academy and Mr. Floyd West of Sulphur Springs High School served as members of a panel on Junior Academies at the meeting of the A.A.A.S., in New York.

Executive Secretary Junior Academy served as advisor to the Toledo Science Day sponsored by the Toledo Technical Council and Toledo Engineering Society.

Respectfully submitted,

Gerald Acker, *Executive Secretary*

REPORT OF TRUSTEES OF THE RESEARCH FUND

Fiscal Year 1961—As of April 7, 1961

Receipts (1960):	
Bank balance Jan 1, 1960	$2,433 45
Interest income	150 00
Dividend income	58 50
A.A.A.S.	650 00
Total receipts as of Dec. 31, 1960	$3,291.95
Expenditures (1960):	
Research grants	550.00
Unexpended balance as of Dec. 31, 1960	$2,741.95
Receipts (1961):	
Bank balance Jan. 1, 1961	$2,741.95
A.A.A.S.	517 00
Total receipts as of April 7, 1961	$3,258 95
Expenditures (1961):	
Permanent Reserve Fund	$2,000 00
Research grant, Eggleston (not used)	100 00
Research grant—Dr. Percy L. Lilly, Non-woody Ranales, the Chenopodioles and Caryophylloles	200.00
Research grant—Edward J. Karlin, Ecological Study of Carnivorous Snails from Hawaii	150 00
Research grant—Joseph Bagshaw, Polymerization and Coacervation of Amino Acids Under Primitive Conditions	75 00
Research grant—Dr. Malcolm P. Weiss, Stratigraphy and Petrology of Flagstaff Limestone in Utah	400 00
Research grant—Dr. Paul S. Stokely, Effects of Growth Compounds on Reconstitution in Planaria	75 00
Total expenditures as of April 7, 1961	$2,975.00
Unexpended balance as of April 7, 1961	$ 283.95

Respectfully submitted,

H. V. Knorr, *Chairman*

REPORT OF THE OHIO FLORA COMMITTEE

The Ohio State University Press announced the publication of "Woody Plants of Ohio" by Dr. E. L. Braun. The selling price is established at $7.50. It is hoped that all Academy members will endeavor to aid the press in promoting the sale of this important contribution to the flora of Ohio.

Dr. E. L. Braun is making excellent progress on "Monocots of Ohio," the first of a series of proposed volumes dealing specifically with the flora of Ohio.

Although a great deal of progress has been made in other areas of the flora project, it cannot easily be reported here. Among the more obvious evidences of progress are as follows:

1) *Rosales* by William Gambill. This project will constitute a major contribution toward Volume II of the Ohio Flora.
2) Pteridophytes of Ohio by Dr. Tom Cooperrider is in progress.
3) *Compositae* of Ohio by Dr. R. W. Long and T. R. Fisher is in progress.
4) Several smaller projects are very promising. Mr. John Speer is well along on the *Asters* of Ohio. Mr. Wingo is working on the *Saxifragaceae* of Ohio. Mr. Hauser is working on the *Rubiales* of Ohio. These smaller projects will contribute greatly to the total effort of the committee.

Respectfully submitted,

T. RICHARD FISHER, *Chairman*

REPORT OF THE ACADEMY HISTORIAN

During the past year the Academy Historian has accomplished the following things: (1) A paper entitled, "The Summer Field Meetings of the Ohio Academy of Science (1892–1905)" was published in the September, 1960, issue of *The Ohio Journal of Science*. (2) A lecture on "George W. Dean and George J. Streator—Pioneer Naturalists of Portage County, Ohio" was given to the Portage County Historical Society in October, 1960. Another lecture scheduled for this same organization will be given in May, 1961, on "Some Pioneer Naturalists of Northeastern Ohio." Included in these two lectures is discussion of eight naturalists who were members of The Ohio Academy of Science during the first year of its operation (two charter members and two of the early officers). (3) Reports were read to the Section of Physics and Astronomy and the Section of Geography at the Antioch meeting, sketching the historical development of those sections. Similar reports will be given to the Sections on Chemistry and Science Education at the Cincinnati Meeting in April, 1961. (4) Membership data for the Academy have been compiled since the report of Alexander in 1943 (*Ohio Jour. Sci.* 41: 300). These are tabulated below. Total membership is an approximation since there are many variable factors. Totals in the files of different offices vary for a number of reasons and the number constantly changes, so that a total figure varies with the date on which the count is made. These approximations, however, gave a clear picture of the growth of the Academy.

Honorary Membership

(this type of membership was created in 1943 and is limited to five at any one time).

William H. Alexander 1943–1960	Edward L. Rice 1949–1960
Edwin S. Moseley 1943–1948	Frank J. Wright 1949–1954
Herbert Osborn 1943–1954	Ethel M. Miller 1955
Frederick O. Grover 1947	Frederick Krecker 1955

Life Members

Ralph Davidson	S. Charles Kendeigh
John B. Gerberich	Floyd A. McClure
J. Arthur Herrick	Mildred Pfeister
David T. Jones	

Approximate Total Membership

1941–520	1948– 850	1955–1223
1942–550	1949– 930	1956–1196
1943–560	1950–1080	1957–1172
1944–570	1951–1040	1958–1272
1945–587	1952–1200	1959–1230
1946–570	1953–1200	1960–1537
1947–700	1954–1160	

Respectfully submitted,

RALPH W. DEXTER, *Chairman*

REPORT OF THE COMMITTEE ON INSTITUTION AND CORPORATION MEMBERS

The number of Institution and Corporation Memberships at the time of the Annual Meeting in Cincinnati was 24; as of May 1, 1961 this number has increased to 25. Each of these members is paying $100 per year.

In 1959, the Academy listed 29 Institution and Corporation Members who were at that time paying $25 annual dues. The membership of this type was only 19 in 1960, when the higher dues went into effect.

A list of the Institution and Corporation members in good standing is printed in each year's November issue of The Ohio Journal of Science.

During the latter part of 1960 and early in 1961, over 250 personal letters were mailed to businesses, industry, and foundations of scientific interest in the State of Ohio. The Com-

mittee appreciates greatly the help of the office of the Executive Secretary in these mailings. These letters solicited not only memberships, but also grants, gifts, and contributions toward the different activities of the Academy. The returns from this campaign were very low, and indicated strongly that personal contacts and visits by the members of the Academy must supplement our direct mailings. The help of the members in this matter is urgently requested, although the Committee will continue using direct mail techniques since they serve as a worthwhile public relations device.

It is strongly felt by the Committee that an effort should be made to at least double the present number of Institution and Corporation Memberships in the Academy.

Respectfully submitted,

P. Rothemund, *Chairman*

REPORT OF THE COMMITTEE ON SCIENCE TEACHER CERTIFICATION

The Committee on Science Teacher Certification met in the Trustee's Room of the Battelle Memorial Institute in Columbus, Ohio, on Saturday, April 15, 1961 at 9:30 AM.

The Committee reconsidered its preliminary recommendations of February 25th in the light of: Dr. Ronneberg's Communication of March 6; discussions with professional educators; and the "Guidelines on State Teacher Certification," which were distributed by Mr. May of the State Office.

As a consequence of these studies the Committee now makes the recommendations which follow and asks that the Council and Executive Committee of the Academy take the steps necessary to encourage and implement their adoption.

COMMITTEE RECOMMENDATIONS

I. Certification Requirements for Secondary Science Teachers.

A. *Provisional Certificate* to teach Secondary Science in the State of Ohio

(1) Minimum requirements for a Science Major Certificate.

a. Bachelor's degree.

b. At least a 24 semester hour major in one of the areas of science.

c. At least 12 semester hours in a related area to the major.

d. At least 8 semester hours in each of the three areas of science and mathematics not covered in b & c (chemistry, physics, biology, earth science and mathematics)

These requirements represent a total of 60 semester hours in science and mathematics.

(2) That all existing science options for certification be eliminated and replaced by the Science Major category.

(3) That no teacher be certified to teach more than his major plus one additional subject. A science major meeting the requirement of (1) would be qualified to teach general science.

B. *Permanent Certificate* to teach Secondary Science in the State of Ohio.

(1) That requirements for the permanent certificate include in addition to the requirements for the Provisional Certificate, *thirty* (30) semester hours of work beyond the Bachelor's degree at *least half* of which must be in *subject matter areas* pertaining to the teaching field.

II. Certification Requirements for Elementary Teachers.

A. That the certification include the following minimums:

(1) Six (6) semester hours of biological science

(2) Six (6) semester hours of physical science

(3) Six (6) semester hours of mathematics.

III. Certification Requirements of All Teachers.

A. That in the near future all teachers certified regardless of classification must have the following as minimums in their training.

(1) Six (6) semester hours of biological science

(2) Six (6) semester hours of physical science

(3) Six (6) semester hours of mathematics.

IV. Other Committee Recommendations.

A. That a new Committee of the Academy be created and designated as the OAS Committee on Science Education. That, with the formation of this new Committee the present one on Teacher Certification be discharged but that some of that committees members (excluding the chairman) be included on the new Committee roster. There are at present many areas of science education which need the Academy's attention. These include: improvement of science laboratory facilities and equipment; improvement of teacher loads and elimination of time consuming non-teaching duties; and improvement of professional orientation of science teachers.

B. That the Academy pass a resolution asking for the following specific improvements regarding science teaching in Ohio Secondary Schools:
   (1) That no science teacher be given a load requiring more than two different class preparations.
   (2) That each science teacher have scheduled one free period per day for laboratory or demonstration preparation.
   (3) That every science teacher be granted time off (and if possible expenses) to attend at least one *scientific* meeting per year.

The school boards and high school administrations should be made cognizant of the importance and rapidly changing nature of science which requires the alert teacher to read, attend meetings etc. in effort to keep updated. No other area of the curriculum can match this need. In addition, the large investment in science laboratories and science equipment should not be neglected because the teacher lacks time to plan for their utmost utilization. His schedule should allow time for proper laboratory planning and the teacher held accountable for doing a creditable job with the facilities available.

The Committee feels that the general attitude of the public toward science education is now such that the Academy should move with dispatch and vigor to implement the changes suggested in this report.

Respectfully submitted,

J. H. BUCKINGHAM, *Chairman*

REPORT OF THE GOVERNOR'S ADVISORY COMMITTEE

Organization: The Committee was organized by letter during January, 1961. It is kept small (5 members) and consists solely of ex-presidents of the Academy.

A first meeting was held March 4, 1961. Only preliminary discussion has been accomplished although some contacts for advice were made in October 1960 and January 1961.

Progress: The Committee invites comments. It is felt that science education in Ohio is still the most critical field of concern although research and atmosphere for scientists are important. A list of contacts through the new Department of Industrial and Economic Development has been set up. It looks as though one man rather than a committee might serve most effectively in advisory capacity to the Governor if a need is established. He might be selected by and be responsible to a commission of 5 or 7. This must be non-political and with Academy sanction. The advisor will need a budget and should probably, therefore, be within one state department. Advice could be channeled on any subject through the Academy office.

Respectfully submitted,

RICHARD P. GOLDTHWAIT, *Chairman*

REPORT OF THE RESOLUTIONS COMMITTEE

Be it resolved that the members of The Ohio Academy of Science express to the Administration of The University of Cincinnati, to Dr. William Dreyer, chairman of the local committee on arrangements, and to the several members of his committee, their appreciation of the excellent facilities and for the thoughtful hospitality which have contributed so greatly to the success of this the Seventieth Meeting of the Academy.

Respectfully submitted,

KENNETH L. KELLEY, *Chairman*

REPORT OF THE NECROLOGY COMMITTEE

In alphabetical order there follows a listing of the deaths that have occurred in the membership of The Ohio Academy of Science in the period April, 1960 to April, 1961.

Respectfully submitted,

J. T. MADDOX, *Chairman*

Dr. Leon Elkanah Smith, 66, Henry Chisholm professor of physics at Denison University since 1928 and president of the Granville Board of Public Affairs, died at 7 AM Sunday, January 22, 1961 in the Veterans Hospital in Dayton, Ohio, where he had been a patient for six weeks.

Death of a heart attack was unexpected, although he had been in failing health the past few months with arthritic complications. He had been unable to teach since last October.

Born June 16, 1894, in Kemper, Ill., he was the son of Jacob E. and Elizabeth (Smith) Smith. In 1908 the family moved to Cherryvale, Kansas and in 1912 Dr. Smith was graduated from high school there.

He taught rural school and served as principal before enrolling at Ottawa University in Kansas. He earned his bachelor of science degree there in 1919 after returning from two years military service with the 130th Field Artillery, 35th division of the AEF, World War I. Dr. Smith saw action in several major battles in France.

After one term of graduate study at the University of Chicago, he was appointed instructor in physics at the University of Pennsylvania where he remained from 1920 to 1928, receiving his Ph.D. degree in 1926.

During World War II, he was in charge of the expanded physics department at Denison University.

Surviving are his widow, the former Anna Kuhn, whom he married in Philadelphia, Pa., June 7, 1922; a daughter, Mrs. Donald J. Bowers, Columbus; a son, Robert D. Smith, Cleveland; also six grandchildren; one sister, Mrs. Fred Brothers of Cherryvale, Kans.,; and one brother, Chalmer O. Smith, Chicago.

At Granville, Dr. Smith served on the Board of Public Affairs for 18 years and was active in Boy Scout work. He had been a member of the Licking County Scout Council and held the Silver Beaver award and was superintendent of the Baptist Sunday School.

He had been president of the Sigma Xi Club of Denison this year and also held memberships in the American Association for the Advancement of Science; Acoustical Society of America; Ohio Academy of Science; American Association of Physics Teachers; Acacia Fraternity, Masonic Lodge; the Valley of Columbus Consistory; American Legion, American Association of University Professors, and was secretary-treasurer of the Ohio section of the American Physical Society.

Funeral services were held in Rhoades Chapel of the First Baptist Church in Granville with burial in the College Cemetery.

Dr. James F. White, 61, Assistant Professor in the chemistry department of Marietta College, died Saturday at 9:10 AM at Marietta Memorial Hospital. His home was at 134 Warner Street.

He was born August 20, 1899, at Berea, a son of the late Rowland and Lura Brown White. In 1923, he married Ruth E. Hoddinott, who survives with one son and two daughters: Dr. George R. White of Long Island, New York; Mrs. Robert A. Shogren of Villa Park, Illinois; and Mrs. Robert I. Moe of Wauwatosa, Wisconsin. There are five grandchildren, Janet, Barbara, and James Shogren and Jennie and Warren Moe. One brother survives, Dr. Dean R. White of Colunia, New Jersey.

Dr. White, was a graduate of Baldwin Wallace College. He received his master's degree and his doctorate degree at Columbia University. He was a veteran of World War I, a member of Sigma Xi Fraternity, the American Chemical Society, The Ohio Academy of Science, the First Methodist Church, the Official Board of the Church, and was chairman of the Commission on Education.

In the summer, he was employed as a ranger naturalist for the National Park Service at the Petrified Forest at Holbrook, Arizona. For 21 years he had been industrial research chemist for the Matheison Chemical Corp. at Niagara Falls. For three years he did research work for Gerber Baby Foods under the direction of the Engineering Experiment Station at Michigan State University and was later chemistry instructor at McMurray College at Abilene, Texas.

Burial was in Mound Cemetery, Marietta.

Dr. David H. Stansbery, Department of Zoology, The Ohio State University, has been appointed Associate Editor of *The Ohio Journal of Science*, effective immediately.